Impacts Assessment of Dynamic Speed Harmonization with Queue Warning

Task 2
Impact Assessment Plan – Final

Version 3.1 – February 2014
Contract: DTFH61-12-D-00044-T-13001

Prepared by
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U.S.Department of Transportation

Intelligent Transportation Systems Joint Program Office

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16. Abstract

The purpose of the Impact Assessment Plan is to take the results of the test track or field tests of the prototype, make reasonable extrapolations of those results to a theoretical full scale implementation, and answer the following 7 questions related to the prototype: (1)When to Implement SPD-HARM Solo or in Combination with Q-WARN?; (2) Which Communication Method is Best for Nomadic (cell phone) Devices?; (3) What are the Impacts of Near, Mid and Long Term Deployment?; (4) What level of market Penetration of connected vehicles is Required for success?; (5) What are the Effects of Communication Errors and Latency?; (6) What are the Benefits of Widespread roadside equipment (RSE) Deployment?: (7) Is Connected Vehicle Data Required for Success of SPD-HARM and Q-WARN?.

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PREFACE

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DISTRIBUTION OF FINAL DOCUMENT

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APPROVAL OF FINAL DOCUMENT

The project management plan has been approved as a work product to be placed under formal change control.

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CONVERSION FACTORS

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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GLOSSARY OF ACRONYMS

API	Application Programming Interface – custom software written to interface with a microsimulation model and perform a specialized function not currently in the microsimulation model.
ConOps	Concept of Operations
DMA	Dynamic Mobility Applications
DOT	Department of Transportation
DSRC	Dedicated Short Range Communications
FHWA	Federal Highway Administración
IA Contractar	Impacto assessment contractor
INFLO	Intelligent Network Flow Optimization
PD Contractor	Prototype development contractor
Q-WARN	Queue warning algorithm or application
RSE	Roadside equipment installed to monitor conditions; collecting traffic flow, density, and speed data and transmitting this information to a data environment (which in turn is accessible by connected vehicles and the transportation management center). Transmission to connected vehicles may be through DSRC or cellular network.
SPaT	Signal phase and timing message sent to vehicle from infrastructure.
SPD-HARM	Speed Harmonization algorithm or application
TMC, TME	Traffic Management Center, Traffic Management Entity
TOPR	Task Order Proposal Request
V2I	Vehicle to Infrastructure communications and the reverse
V2V	Vehicle to Vehicle communications.
V2X	Vehicle to vehicle and vehicle to infrastructure communications and the reverse

EXECUTIVE SUMMARY

This document is the Task 2 deliverable, the Impact Assessment Plan, for the task order: Impacts Assessment of Dynamic Speed Harmonization with Queue Warning (Contract: DTFH61-12-D-00044). The purpose of this task order is to:

(i) Assess the impacts of a prototype of Dynamic Speed Harmonization (SPD-HARM) with Queue Warning (Q-WARN), which are two component applications of the Intelligent Network Flow Optimization (INFLO) bundle (The prototype is being developed by the Prototype Development - PD Contractor), and

(ii) Assess the impacts of the prototype at various levels of potential future market acceptance on the facility where a small-scale demonstration of the prototype will be conducted.

This Impact Assessment (IA) Plan addresses the following topics identified in the project management plan:

- Hypotheses to be tested during the demonstration/test of the prototype.
- Hypotheses to be tested for a large-scale deployment of the applications, if a small-scale demonstration is conducted by the PD Contractor.
- Hypotheses to be tested using a facility proposed by the research team, if the PD Contractor does not conduct a small-scale demonstration of the prototype.
- Performance measures and targets.
- Assumptions that will be used for the impacts assessment.
- Performance and explanatory data (“before” and “after”) not generated within the prototype system that need to be collected, and the process by which the data will be collected.
- Processes for verifying data quality and for cleaning data, and minimum thresholds for data quality.
- Methods for collecting feedback from stakeholders and demonstration/test drivers, processing and analyzing feedback, and integrating the results into the assessment of the impacts of the prototype as well as a large-scale deployment.
- Processes for estimating or simulating the impacts of the prototype demonstration/test, including a detailed traffic simulation study potentially supported by a range of statistical analyses and driver-behavior studies.
- Processes for extrapolating, inferring, estimating, or simulating the impacts of a future deployment of the prototype system at various levels of potential future market acceptance.
- Identify what data are intended to be broadly shared on the RDE and what data elements are proprietary or include personally identifiable information (PII).

At the time of preparation of this draft of the Impact Assessment Plan several key issues on the SPD-HARM prototype and its testing are still be finalized. The document has been updated based on updated information received about the prototype, and comments from USDOT representatives and stakeholders.

MEASURES OF EFFECTIVENESS

The measures of effectiveness identified in the INFLO Concept of Operations document, the issues associated with them, and the recommended performance measures for the Impact Assessment are summarized in **Error! Reference source not found.** (see Chapter 2 for etails).

Table 1. Performance measures, issues, recommendations (summary).

ConOps Performance Measure	Issues	Recommendation
Shockwaves:	Useful for diagnosis, but too detailed to compare.	Examine shockwaves, but report only maximum speed differences.
Queues: Length and Duration	Useful for diagnosis, but too detailed to compare.	Examine queues, but report Vehicle-Hours in Queue (VHQ).
Throughput (veh per hour)	Should also be compared to demand.	Report Vehicle-Miles Traveled (VMT) (demanded and served)
Speed Variance	Increased by speed smoothing	Report maximum speed differences between sublinks.
Average Travel Time	Good summary measure	Report vehicle hours traveled/trip.
Reliability measure	Buffer time undependable	Report 95^{th}% Travel Time Index
Environmental Effects - Estimated CO2 equivalent emissions - Estimated fuel consumption (gallons)	Data intensive unless assumptions employed.	Employ assumptions. Report percentage changes.
User Acceptance - Market penetration - Compliance with speed messages	Available resources insufficient to test user acceptance.	Conduct sensitivity tests of market penetration and compliance.
Safety Effects - Number of Crashes - - Severity of Crashes -	Microsim proxies are not well related to real safety effects.	Discuss qualitatively the likely safety effects of reduced speed variance and time in queue.

DEVELOPMENT OF THE EXPERIMENTAL PLAN

The development of the experimental plan considered the key questions identified in the Task Order Proposal Request (TOPR) (See Chapter 3 for details):

- When to Implement SPD-HARM Solo or in Combination
- Which Communication is Best for Nomadic Devices
- What are the Impacts of Near, Mid and Long Term Deployment
- What level of market Penetration is Required
- What are the Effects of Communication Errors and Latency
- What are the Benefits of Widespread RSE Deployment
- Is Connected Vehicle Data Required for Success

These questions were converted into hypotheses and the Impact Assessment Plan developed for testing them.

Given the multidimensional nature of the hypotheses it was necessary to develop a strategic sampling and testing plan to preserve resources. The proposed testing plan groups factors by causality chains so that variations in each individual factor do not have to be exhaustively simulated, only variations in the results of the several factors acting together are simulated.

For example, rather than simulate different market penetration rates, different communication loss rates (and latencies), and different compliance rates, these factors are combined into a single response rate. Different levels of response are explicitly simulated. Then the contributions of each factor (penetration, communication loss, latency, and compliance) are evaluated separately by post processing the simulation results for each of the response levels simulated in the simulation model runs.

THE EXPERIMENTAL PLAN

The proposed Impact Assessment Experimental Plan is shown in Table 2 (see chapter 4 for details). A total of 7 tests are planned to address the 7 questions posed in the TOPR.

- Test #2, the evaluation of under what operational conditions the applications are most beneficial, is the core test to be conducted under this Impact Assessment Plan.
- The remaining Tests (#1, 3, 4, 5, 6, 7, 8) consist of numerical evaluations, extrapolations, and application of probabilistic and combinatorial analysis to the results of Test #2.

Test #2 consists of a series simulation experiments (model runs, each with multiple repetitions) to estimate the changes in the measures of effectiveness (MOE's) under a variety of operating conditions and response rates.

The response rates are in turn a function of market penetration, communication loss, communication latency, and compliance. Thus we can meet the objectives of the Impact Assessment Plan by running the simulations for different levels of response rates, and then post-process the results to determine how different assumptions of market penetration, communication loss, and compliance affect the response rate and therefore the MOE results.

Table 2. Impact assessment experimental plan (summary).

Test	Objective	Method	MOE's
1	Determine if SPD-HARM and Q-WARN bundles are more effective combined then individually	Examine numerically the Test #2 results.	Same as Test #2
2	Under what operational conditions are the applications most beneficial?	IA contractor to design and conduct a multi-dimensional simulation test program.	See in Performance Measures and Targets
3	When is DSRC needed and when will cellular suffice?	Examine Test #2 results to obtain sensitivity of different communication latencies	Same as Test #2.
4	Determine impacts of near, mid, long term deployment.	Examine numerically the Test #2 market penetration results.	Same as Test #2.
5	Determine required level of market penetration	Examine numerically the Test #2 market penetration results.	Same as Test #2.
6	Determine effects of communications errors and latency	Examine numerically the Test #2 results for latency and communication errors.	Same as Test #2.
7	Determine benefits of widespread RSE	Examine numerically the Test #2 results. Consider Test #3 conclusions.	Same as Test #2.
8	Determine extent to which V2X is required	Examine numerically the Test #2 results. Consider Test #3 conclusions.	Same as Test #2.

COOPERATIVE FEATURES

The success of certain aspects of the Impact Assessment Plan hinge on the data to be delivered by the PD Contractor and/or FHWA. With respect to the PD Contractor's optional tasks (the Controlled Environment Test or the Small Scale Demonstration) the following data would improve the value of the impact assessment:

1. For the Controlled Environment Test Experimental Plan (if elected by FHWA)
    a. Connected Vehicle data
        i. Second by second vehicle trajectory data for connected test vehicles.
        ii. Second by second SPD-HARM/Q-WARN message content and display status for each test vehicle (message logs for each vehicle).
    b. Algorithm Performance Data
        i. Sensitivity tests of the effect on algorithm performance of different values of user definable parameters
2. For the Small Scale Demonstration Experimental Plan (if elected by FHWA)
    a. Infrastructure data
        i. "Before and during demo" data on weather, incident logs, traffic speeds and volumes for each segment of the facility.
        ii. Message logs (message with time stamp) for changeable message signs (CMS).

b. Connected Vehicle data

    i. Second by second vehicle trajectory data for connected test vehicles.
    ii. Second by second SPD-HARM/Q-WARN message content and display status for each test vehicle (message logs for each vehicle).

c. Algorithm Performance Data

    i. Sensitivity tests of the user definable algorithm parameters selected for the tests.
    ii. Event detection and message logs for central processor showing time of detection, message selected, time of message dissemination, target vehicles and target CMS signs for message.
    iii. PD team's assessment of accuracy of event detection and message sent (rates of missed events, false alarms, incorrect message selection, etc.) under various user definable parameters and conditions.

CHAPTER 1. INTRODUCTION

The USDOT Dynamic Mobility Applications (DMA) Program focuses on exploiting new forms of data from wirelessly connected vehicles, travelers, and the infrastructure to enable transformative mobility applications including advanced information systems for travelers and freight, incident management systems, and advanced management systems for highway facilities, transit, and signal control systems. Dynamic Speed Harmonization (SPD-HARM) and Queue Warning (Q-WARN) are two component applications of the Intelligent Network Flow Optimization (INFLO) bundle of the (DMA) program.[1]

PURPOSE OF IMPACT ASSESSMENT PLAN

The purpose of the Impact Assessment Plan is to take the results of the test track or field tests of the prototype, make reasonable extrapolations of those results to a theoretical full scale implementation, and answer the following 7 questions related to the prototype:

- When to Implement SPD-HARM Solo or in Combination with Q-WARN?
- Which Communication Method is Best for Nomadic (cell phone) Devices?
- What are the Impacts of Near, Mid and Long Term Deployment?
- What level of market Penetration of connected vehicles is Required for success?
- What are the Effects of Communication Errors and Latency?
- What are the Benefits of Widespread roadside equipment (RSE) Deployment?
- Is Connected Vehicle Data Required for Success of SPD-HARM and Q-WARN?

The prototype algorithms and the concepts behind them are described below.

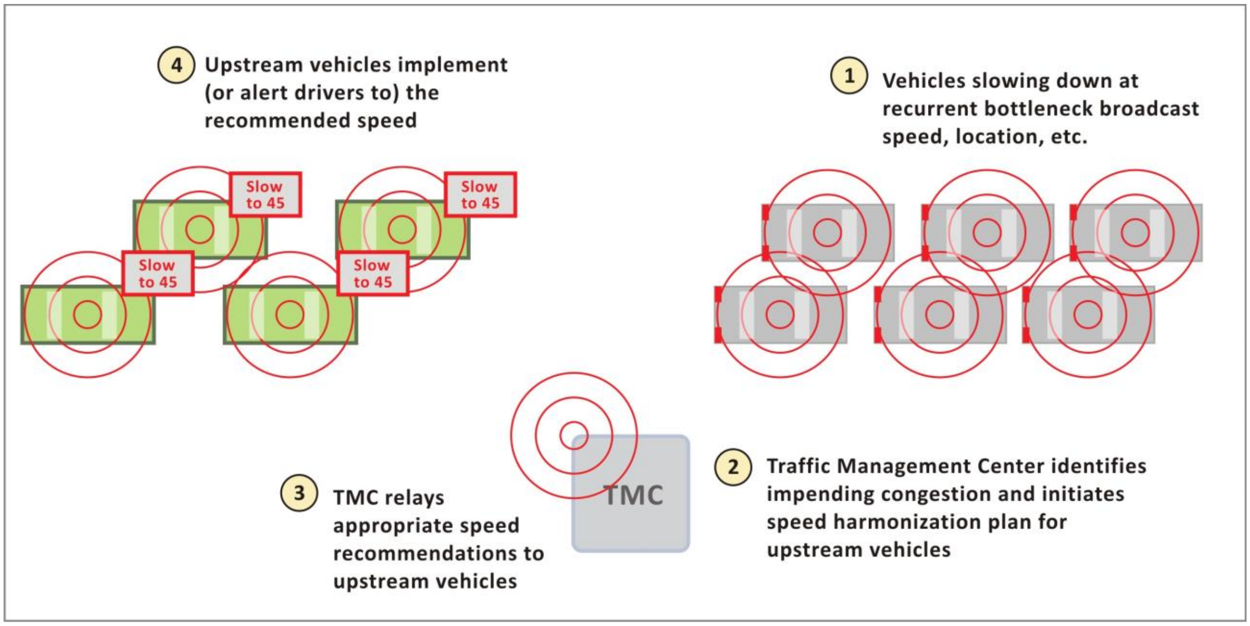
THE SPD-HARM APPLICATION CONCEPT

In concept, speed harmonization of traffic flows in response to downstream congestion, incidents, and weather or road conditions can greatly help to maximize traffic throughput and reduce crashes. The INFLO SPD-HARM application concept aims to realize these benefits by utilizing connected vehicle V2V and V2I communication (collectively called V2X or connected vehicles) to detect the precipitating roadway or congestion conditions that might necessitate speed harmonization, to generate the appropriate response plans and speed recommendation strategies for upstream traffic, and to broadcast such recommendations to the affected vehicles.

The overall concept for the SPD-HARM application is illustrated in **Error! Reference source ot found.**. Roadway sensors and connected vehicles transmit information on vehicle speeds, flow rates, and occupancy to the traffic management center (TMC). A road weather information system (RWIS) transmits facility information on visibility, coefficient of pavement-tire friction, temperature (air and road surface), humidity, wind speed, pressure, and precipitation to the

[1] “Concept Development & Needs Identification for Intelligent Network Flow Optimization (INFLO): Concept of Operations,” Final Report FHWA-JPO-13-012, June 2012.

connected vehicle and/or the TMC. The SPD-HARM application detects the presence of a mobility problem or predicts an imminent mobility problem based on heavy flow rates. The TMC applies a response generation algorithm within the SPD-HARM application to suggest speed recommendations for upstream vehicles and other recommended actions on the part of the TMC. This algorithm identifies the timing, location, and recommended speeds for transmission. The speed recommendations are transmitted to the vehicles on the facility.



Source: Concept of Operations, Concept Development and Needs Identification for Intelligent network Flow Optimization*, Final Report, FHWA-JPO-13-012, June, 2012.*

Figure 1: Illustration. SPD-HARM concept with connected vehicles.

THE SPD-HARM PROTOTYPE TO BE EVALUATED

The SPD-HARM prototype to be evaluated in this Impact Assessment has the following features:[2]

- Existing average traffic speeds by direction for each 1/10th mile long sublink of the facility are gathered from both infrastructure sensors and connected vehicles.
    - In cases of conflicts between road sensors and connected vehicles, the lower speed controls.
- Adjacent sublinks with similar mean speeds (falling within a speed range specified by the agency operator) are grouped together into "troupes."

[2] Kevin Balke, Hassan Charara, Srinivasa Sunkari; draft Report on Dynamic Speed Harmonization and Queue Warning Algorithm Design, Texas A&M Transportation Institute, FHWA, Washington, DC, January 15, 2014.

- The recommended speed for each “troupe” is set at the average speed for that troupe rounded up to the nearest 5 mph increment, subject to:
  - Agency specified maximum and minimum speed values for the sublinks cannot be exceeded.
  - The recommended speed cannot exceed the recommended maximum speed for weather conditions.
  - Differences in recommended speeds between adjacent troupes greater than 5 mph must be transitioned through the sublinks bordering the two adjacent troupes.
  - The recommended speed for any sublink cannot change more often than once every 15 seconds.
- The recommended connected vehicle speeds should be the same as that displayed on any roadway variable speed signs.
- Recommended speeds are advisory, not regulatory.

Note that there are slight differences between the SPD-HARM Application concept and its prototype.

- The SPD-HARM prototype is always operational. There is always a recommended speed displayed for every sublink of the facility.
- The SPD-HARM prototype does NOT predict events nor speeds, and only recommends a speed significantly different than the measured average speed in the case of bad weather.

THE Q-WARN APPLICATION IN CONCEPT

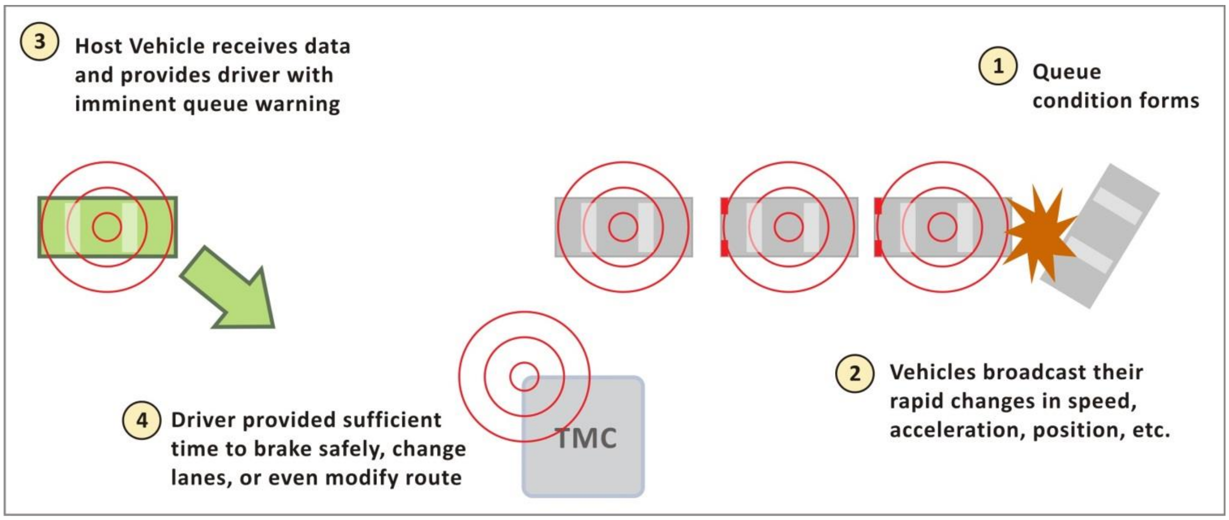
Queuing conditions present significant safety concerns, particularly with the increased potential for rear-end collisions. They also present disruptions to traffic throughput by introducing shockwaves into the upstream traffic flow. The INFLO Q-WARN application concept aims to minimize the occurrence and impact of traffic queues by utilizing connected vehicle technologies, including vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communications, to enable vehicles within the queue event to automatically broadcast their queued status information (e.g., rapid deceleration, disabled status, lane location) to nearby upstream vehicles and to infrastructure-based central entities (such as the TMC) in order to minimize or prevent rear-end or other secondary collisions.

The overall concept for the Q-WARN application is illustrated in Figure 2. Just as for the SPD-HARM application, under the Q-WARN application, roadway sensors and connected vehicles also transmit information on vehicle speeds, flow rates, and occupancy to the traffic management center (TMC).

THE Q-WARN PROTOTYPE TO BE EVALUATED

The Q-WARN prototype to be evaluated in this Impact Assessment has the following features:[3]

- Existing average traffic speeds by direction for each 1/10th mile long sublink of the facility are gathered from both infrastructure sensors and connected vehicles.
- If a sufficient number and percent of roadway lane sensors or connected vehicles meet a user set maximum speed threshold for being in queue state for a user set sufficient length of time (to avoid false alarms), then the sublink is determined to be in queue state.
    - In case of conflicts between roadway sensors and connected vehicles, the lower speed controls.
- For each queue a queue warning message is broadcast to all connected vehicles within a user specified distance upstream of the back of the queue.
- The message states the distance between the vehicle and the back of the queue.



Source: Concept of Operations, Concept Development and Needs Identification for Intelligent network Flow Optimization*, Final Report, FHWA-JPO-13-012, June, 2012.*

Figure 2: Illustration. The Q-WARN application (concept).

One difference between the concept and the prototype for Q-WARN is that in the prototype, connected vehicles will NOT know which lane they are in.

[3] Kevin Balke, Hassan Charara, Srinivasa Sunkari; draft Report on Dynamic Speed Harmonization and Queue Warning Algorithm Design, Texas A&M Transportation Institute, FHWA, Washington, DC, January 15, 2014.

CHAPTER 2. PERFORMANCE MEASURES AND TARGETS

The Concept of Operations document (ConOps) for INFLO lists several performance measures for SPD-HARM and Q-WARN to quantify the objectives of safety, mobility and energy/environment. The objective of this Impact Assessment plan is to obtain these performance measures (or their proxies) from a combination of the controlled environment test or the small scale demonstration test plus a simulation tool to extend the results to a wider range of possible conditions.

Table 3 lists the INFLO ConOps performance measures, the issues involved in their measurement, and suggested solutions for use in the Impact Assessment. The discussion below explains the entries in this table.

Before discussing the measures, there are two fundamental points to be made:

- No performance targets are set in this Impact Assessment Plan. That is not the purpose of this assessment. Performance targets will be determined by the users of the Impact Assessment results.
- The output from a microsimulation model will be the primary source of performance measures for evaluating the prototype because the model enables the evaluation of the effects of several factors in a controlled setting.
    - The small scale demonstration, if selected by FHWA, will provide corroborating information for a specific case in the field for validating the microsimulation analysis.
    - The controlled environment test, if selected by FHWA, will provide information on some of the technological aspects of the prototype (useful for setting some model parameters), but, by its very nature (being a controlled environment) it is not anticipated to provide significant performance results for the evaluation.

SHOCKWAVES

One of the objectives of SPD-HARM and Q-WARN is to improve safety by giving drivers advance warning of downstream queues and smoothing out the speeds of vehicles on the facility. Consequently the ConOps recommended that reduction of the frequency and severity of speed shockwaves in the traffic stream be used as a direct measure of the speed smoothing effects and therefore an indirect measure of the safety effects.

A shockwave is generated when downstream traffic density is greater than upstream density. It is indicated by an abrupt change in the speeds of vehicles.

Table 3: Performance Measures, Issues, Recommendations

ConOps Performance Measure	Issues	Recommendation for IA Plan
Shockwaves: Number of shockwaves formed, Length (duration), propagation speed	Useful for diagnostic work, but hard for reader to compare across alternatives.	Examine shockwaves, but report maximum speed difference between adjacent sublinks.
Queues: Length and Duration	Useful for diagnosis, but hard to compare multiple queues and durations across Alts.	Examine queues, but report Vehicle-Hours in Queue (VHQ).
Throughput (veh per hour)	Good summary measure. Should also be compared to demand.	Report Vehicle-Miles Traveled (VMT) (demanded and served)
Speed Variance	Increases with speed smoothing	Report instead the maximum speed difference between adjacent sublinks.
Average Travel Time	Good summary measure	Report vehicle hours traveled (VHT) per vehicle, including entry delay.
Reliability measure: Buffer time or Planning time index--95th Percentile Travel Time Index	Buffer time can behave unexpectedly when comparing alternatives	Report 95th Percentile Travel Time Index (TTI).
Environmental Effects - Estimated CO2 equivalent emissions - Estimated fuel consumption (gallons)	Requires some strong assumptions to do at macroscopic level.	Report differences (delta's) between alternatives.
User Acceptance & Compliance - Market penetration - Compliance with speed messages - Ratings in public opinion surveys	The available resources insufficient to test or survey user acceptance.	Conduct sensitivity tests of different penetration rates and compliance rates.
Safety Effects - Number of Primary and Secondary Crashes - Severity of Crashes	According to stakeholders, the proposed proxies are not well related to actual safety effects.	Discuss qualitatively the likely safety effects of reduced speed variance and time in queue.

Loop detector data (or similar data from other detector technologies) can be used in the field and in the microsimulation model to identify bottlenecks[4], determine the spatial and temporal extent of the congestion and obtain estimates of the shockwave speeds[5]

Identification and tallying of shockwaves (number, duration, propagation speed) is certainly feasible in a microsimulation environment through the processing of the vehicle trajectory data output. The size of the vehicle trajectory data files to be processed is not trivial, but probably the biggest challenge will be interpreting the multi-dimensional results. Are fewer shockwaves of longer duration preferable to the reverse? What is an acceptable number of, and duration for shockwaves? How should higher or lower shockwave propagation speeds be interpreted?

The detailed shockwave information is useful for achieving a better understanding of the mechanisms involved in producing the observed results with SPD-HARM and Q-WARN. Consequently it is recommended that the shockwaves be visually inspected by the research team during the microsimulation evaluation process to better diagnose the causes of the observed effects.

However, detailed shockwave information is difficult to convey in summary form to readily assess if the prototype performed better, under one set of conditions or the other. Consequently it is recommended that the maximum speed difference observed between adjacent sublinks be used as the proxy performance measure for shockwaves, when reporting the overall benefits and disbenefits of SPD-HARM and Q-WARN. A lower maximum subline speed difference for the facility as a whole indicates that the prototype is achieving its objective of reducing extreme speed variations, reducing shockwaves, and indirectly improving safety. The examination of shockwave details by the research team will be used to explain the observed effects on overall speed variance and to better characterize the results.

QUEUE LENGTH AND DURATION

Like shockwaves, queue lengths and durations are another example of detailed microsimulation output valuable for diagnosing the causes of observed phenomena, but potentially confusing for interpreting overall results. Consequently, it is recommended that the research team inspect how queue lengths and duration of queue vary with SPD-HARM and Q-WARN under varying conditions, and report any conclusions on the underlying causes of the observed effects of these algorithms. However, for the purposes of comparing overall performance between alternatives, it is recommended that Vehicle-Hours in Queue (VHQ) be reported for each simulation test. This summary measure should track the overall facility-wide effects of the algorithms.

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[4] Chen, C., A. Skabardonis and P. Varaiya, “Systematic Identification of Freeway Bottlenecks,” Transportation Research Record #1867, Journal of the Transportation Research Board, 2004

[5] Wieczsorek, J, H. Li and R. Bertini, “Integrating an Automated Bottleneck Detection Tool into an Online Freeway Data Archive,” 88th TRB Annual Meeting, Washington DC, January 2009.

THROUGHPUT

It is recommended that throughput be reported for each test in terms of vehicle miles traveled (VMT). Two values of VMT should be reported – VMT demanded and VMT served. VMT demanded is determined by multiplying each cell in the facility's origin-destination (OD) table by the length of the shortest path between the two points and summing the results over the entire OD table. VMT served is obtained by tallying the distances the vehicles actually moved within each link and summing the results across all vehicles and links. The difference between the two indicates either the unserved demand (if VMT served is less than VMT demanded) or the wasted VMT due to rerouting of traffic to longer routes (If VMT served is greater than VMT demanded). This difference will also serve a valuable diagnostic function. Once VMT served equals VMT demanded, further increases in throughput cannot be expected, no matter the improvements to facility capacity or operation.

VARIANCE OF SPEEDS

Initial hypothetical tests of the SPD-HARM prototype suggest that the computed variance for the facility will increase with SPD-HARM, rather than decrease. So speed variance may not be a desirable performance measure for the prototype.

Source: Kittelson & Associates/USDOT

Figure 3 illustrates the likely impacts of SPD-HARM on the variance of sublink speeds for a theoretical bottleneck.

- The top drawing shows a theoretical freeway flowing from left to right with increasing time in the vertical dimension. Speeds in the bottleneck sublink gradually decrease until the bottleneck reaches capacity. At that point speeds are 35 mph within the bottleneck. Once the bottleneck reaches capacity, a queue starts to build up, upstream of the bottleneck (as evidenced by speeds in the 15 mph to 30 mph range). After a while demand starts to drop off and eventually the queue clears, at which point speeds within the bottleneck start to increase back up to the 70 mph free-flow speed for this hypothetical example.
- The bottom drawing shows the likely effects of the SPD-HARM prototype with speed differentials between adjacent sublinks limited to 5 mph. The effect is to spread the speed effects of the bottleneck further upstream and downstream of the bottleneck.
    - Note that there is still a significant time shear between recommended speeds for the same sublink between time slices (a rapid large magnitude change in recommended speed). This is unavoidable, because the SPD-HARM prototype cannot predict queueing, but must instead react to it. Reducing the time shearing effect would require increasing the geographic shearing effect between adjacent sublinks.

The net result of this hypothetical example is that SPD-HARM (in this particular instance) results in a net reduction in mean speed (from 66.5 to 61.7 mph) and a net increase in the standard deviation of speeds (11.1 to 13.7 mph) between sublinks and time slices. However, SPD-HARM has reduced the maximum speed difference between adjacent sublinks from 20 mph to 5 mph, a desired effect of the prototype.

Thus this hypothetical example and additional hypothetical tests of much less aggressive SPD-HARM options by the IA team (not documented here) suggest that speed variance may NOT be a desirable performance measure for the prototype. Instead the maximum difference in mean speeds between adjacent sublinks (each on the order of 1/10th of a mile in length) is recommended as the superior performance measure.

Without SPD-HARM — Mean= 66.50 mph — StDev= 11.14 mph — CofV= 16.8% — MaxD= 20 mph

	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
	70	70	70	70	70	70	70	70	70	70	70	70	70	70	65	70	70	70	70	70	70	70
	70	70	70	70	70	70	70	70	70	70	70	70	70	70	60	70	70	70	70	70	70	70
	70	70	70	70	70	70	70	70	70	70	70	70	70	70	55	70	70	70	70	70	70	70
	70	70	70	70	70	70	70	70	70	70	70	70	70	70	50	70	70	70	70	70	70	70
	70	70	70	70	70	70	70	70	70	70	70	70	70	65	45	65	70	70	70	70	70	70
	70	70	70	70	70	70	70	70	70	70	70	70	70	60	40	60	70	70	70	70	70	70
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	70	70	70	70	70	70	70	70	70	70	70	70	70	70	50	70	70	70	70	70	70	70
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	70	70	70	70	70	70	70	70	70	70	70	70	70	70	60	70	70	70	70	70	70	70
	70	70	70	70	70	70	70	70	70	70	70	70	70	70	65	70	70	70	70	70	70	70
Time	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70

Distance Downstream — Direction of Flow --> — Bottlenck

With SPD-HARM — Mean= 61.67 mph — StDev= 13.74 mph — CofV= 22.3% — MaxD= 5 mph

	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
	70	70	70	70	70	70	70	70	70	70	70	70	70	70	65	70	70	70	70	70	70	70
	70	70	70	70	70	70	70	70	70	70	70	70	70	65	60	65	70	70	70	70	70	70
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	70	70	70	70	70	70	70	70	70	70	70	70	70	70	65	70	70	70	70	70	70	70
Time	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70

Distance Downstream — Direction of Flow --> — Bottlenck

Source: Kittelson & Associates/USDOT

Figure 3: Graph. Theoretical impacts of SPD-HARM prototype on sublink speeds near a bottleneck.

AVERAGE TRAVEL TIME

The total number of vehicle-hours (VHT) accumulated by vehicles using, and attempting to use the facility during the simulation period will be reported. This value will be divided by the number of vehicles using or attempting to use the facility to obtain an average travel time per vehicle. Vehicles attempting to use the facility are those prevented from entering the facility due to queues backing up onto the on-ramps or onto the mainline entry point.

RELIABILITY

The INFLO ConOps identified Buffer Time and the Planning Time Index as potential reliability performance measures.

- The Buffer Index is the difference between the 95th percentile travel time and the average (or median) travel time divided by the average travel time (or the median travel time).[6]
- The Planning Time Index is the 95th percentile highest travel time divided by the free-flow travel time.

According to the SHRP2-L08 project, "The buffer index can be an unstable indicator of changes in reliability because it can move in a direction opposite to the mean and percentile-based measures. This occurs because it uses both the 95th percentile and the median or mean travel time, and the percent change in these values can be different from year to year."

Accordingly, the Planning Time Index is recommended as the reliability performance measure for the purposes of the Impact Assessment.

ENVIRONMENTAL EFFECTS

Table 8-1 of the INFLO ConOps identified the estimated carbon dioxide equivalent emissions and estimated fuel consumption as potential environmental performance measures for SPD-HARM.

Emission rates for vehicles are affected by numerous environmental factors not directly related to speed harmonization or advanced queue warning. These environmental factors include: ambient temperature, vehicle mix (age and size of vehicle and fuel source), humidity, altitude, and the emission control requirements of the particular state in which the facility is located.

The vehicular emissions of hydrocarbons, Carbon Monoxide and Carbon Dioxide then must be converted into their Carbon Dioxide equivalent based onto the comparative greenhouse warming effects.

Since it is not desirable to devote an extensive amount of evaluation resources to emissions analysis, it is recommended that a single set of default assumptions regarding the environmental factors, representative of average conditions in the continental United States be adopted for the purposes of the Impact Assessment. The Impact Assessment results would then be reported in terms of percentage changes in fuel consumption and CO2 equivalent emissions, instead of actual tons or gallons.

[6] Kittelson, Wayne; Mark Vandehey; SHRP 2 Reliability Project L08, Incorporation of Travel Time Reliability into the HCM, Prepublication Draft, Unedited, Transportation Research Board, Washington, DC, August 2013.

USER ACCEPTANCE & COMPLIANCE

The INFLO ConOps identified the desirability of measuring user acceptance in some manner. Compliance rate with posted or recommended speeds was one recommended measure. A second suggested measure was “ratings on public opinion surveys.”

The available resources do not allow a marketing or public acceptance survey to be conducted, nor will they support recruitment of a sufficient sample of drivers to estimate the likely compliance rate with speed harmonization messages by the general public.

Consequently it is proposed for the Impact Assessment that sensitivity tests be conducted of different market penetration and compliance rates. Likely public opinions on the bundles will be discussed tentatively and qualitatively.

SAFETY EFFECTS

The INFLO ConOps identified several measures of the safety effects, including: number of primary crashes, severity of crashes, and number of secondary crashes. The typical microsimulation modeling environment is not suitable for predicting changes in crash rates and severity. In addition, the quantifying the reduction of crashes before and after the implementation of the prototype in the field requires multi-year data collection. Therefore, our analysis must be based on metrics that can be correlated with increased risk of rear-end crashes.

Recent statistical analyses of crashes on urban freeways using limited real-time travel data has shown that the risk of rear-end crashes increases with variation in individual vehicle speeds, variation in individual vehicle headways and vehicle spacing in the congested queue.

There are several surrogate measures that have been proposed and tested in the literature[7],[8],[9] including maximum decelerations, speed gradient, time-to-collision, crash potential (combination of speed variance at a point, traffic density and speed gradient), and combination of speed and deceleration.

Two surrogate measures were initially considered as proxies for crashes:

- Number of instances where adjacent vehicles have a speed difference of greater than 10 mph.

[7] Gettman, D. and L. Head, “Surrogate Safety Measures from Traffic Simulation Models, “Transportation Research Record #1840, Journal of the Transportation Research Board, 2003.

[8] Ozbay, K. et al, “Derivation and Validation of a New Simulation Based Surrogate Safety Measure,” Transportation Research Record #2083, Journal of the Transportation Research Board, 2008.

[9] Lee, C., B. Hellinga and F. Saccomanno, “Assessing Safety Benefits of Variable Speed Limits,” Transportation Research Record #1897, Journal of the Transportation Research Board, 2004.

- Number of instances where adjacent vehicles are within 2 seconds headways of each other.

Neither measure was considered a satisfactory surrogate measure for crashes by at least one of the stakeholder reviewers of an earlier draft of this Impact Assessment Plan. In fact, given the available microsimulation tools and the short time frame for any field work, it was recommended that the Impact Assessment not attempt to make any safety claims beyond the capabilities of the proposed impact assessment methodology. Consequently, it is recommended that the Impact Assessment address qualitatively the likely safety effects based on simulated changes in the speed variance for traffic on the facility.

ADDED DATA ITEMS FOR MICROSIMULATION TESTS

As part of the performance measures gathered during the microsimulation tests, the plan is to tally and report the following additional statistics:

- Latent delay (the delay accrued by vehicles prevented from entering the network by queues.
- Number of stops experienced.
- We will look into reporting the frequencies of near conflicts to the extent that the car-following model in the microsimulation model would make this information meaningful for assessing likely safety effects.
- We will look into reporting number of lane changes from the microsimulation model runs to the extent this can be meaningfully correlated to safety effects.
- We will conduct sensitivity tests of different weather and incident probabilities.

CHAPTER 3. DEVELOPMENT OF THE EXPERIMENTAL PLAN

This chapter explains the development of the recommended experimental plan to assess the impacts of SPD-HARM and Q-WARN. We describe the seven sets of key questions identified in the Task Order Proposal Request (TOPR) that are listed on page 13 under Task 2 in the O&ITS-13-07 TOPR Statement of Work. We provide hypotheses, assumptions and suggestions regarding how they might be addressed within the framework of the impact assessment.

The objective of impact assessment (IA) of the SPD-HARM with Q-WARN is to address as many of the questions identified in the TOPR as feasible given the resources available for the IA, and the limitations of the proposed small scale demonstration or controlled environment testing of the SPD-HARM/Q-WARN prototype.

Note that this impact assessment is specific to the prototype being developed and not to the SPD-HARM and Q-WARN concepts described earlier. Details of the prototype to be evaluated are given in Appendix B, which fills in some of the computational details of the Design Document. [10]

QUESTION 1: WHEN TO IMPLEMENT SPD-HARM AND Q-WARN SOLO OR IN COMBINATION

- This first question set in the TOPR consists of the following questions:
- (1a) Are speed harmonization and queue warning applications more beneficial when implemented in conjunction or in isolation?
- (1b) Under what operational conditions are the applications the most beneficial?
- (1c) Under what conditions is one application superior to the other?

Question 1a Are speed harmonization and queue warning applications more beneficial when implemented in conjunction or in isolation?

The operational hypotheses here are:

- *SPD-HARM and Q-WARN will individually produce benefits even when implemented solo, without the other application.*
- *SPD-HARM and Q-WARN will produce higher benefits and perhaps synergistic benefits when deployed in combination*

The answer to these questions and hypotheses will be determined by examining the results of the tests performed under Question 1b.

[10] Kevin Balke, Hassan Charara, Srinivasa Sunkari; draft Report on Dynamic Speed Harmonization and Queue Warning Algorithm Design, Texas A&M Transportation Institute, FHWA, Washington, DC, January 15, 2014.

Question 1b Under what operational conditions are the applications the most beneficial?

The operational hypothesis here is that:

- There are some operational conditions under which SPD-HARM and Q-WARN are most effective and these conditions might vary depending on whether each application is implemented solo or in combination.

This is a multi-dimensional hypothesis that will require simulation testing of the two applications under differing traffic operating and weather conditions. These conditions may include varying recurrent congestion levels due to varying demand levels, varying visibility, varying pavement friction coefficients, varying non-recurrent congestion (incident, weather, etc.) conditions, varying geometric conditions (sight distance, vertical and horizontal curvature, lane widths, shoulder widths), varying roadside and in-vehicle distractions, density of the roadside equipment (RSE) for detecting traffic conditions, varying communication errors and latency, degree and quality of guidance provided the connected vehicles, and varying market penetration rates for the connected vehicles.

Due to the multiple dimensions involved, answering this one question (1b) in detail could fully exhaust the study. Thus it is necessary to reduce the many dimensions of the problem.

One way to do this is to identify how the many factors might affect vehicle operation and response with SPD-HARM/Q-WARN and to group the effects into tiers or levels. Then it is possible to combine the consideration of multiple factors into a few levels of a few causal factors.

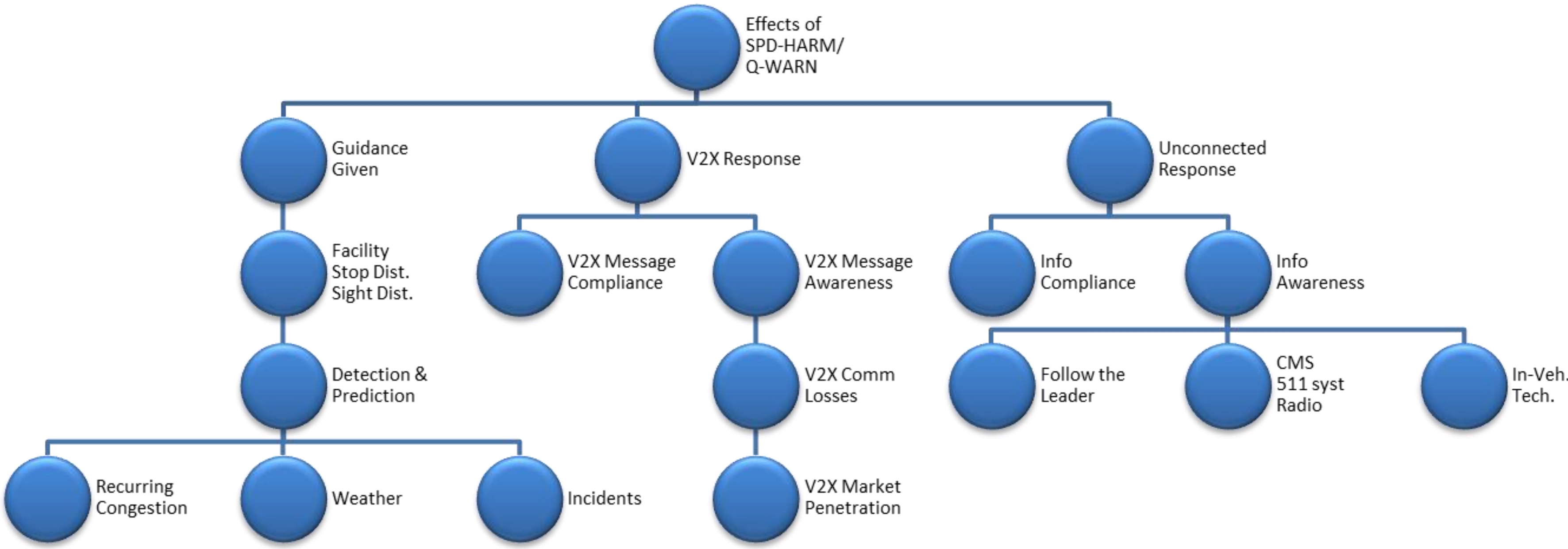
Source: Kittelson & Associates/USDOT

Figure 4 shows a proposed tree of causality factors for estimating the effects of the SPD-HARM and Q-WARN applications under varying operating conditions. It breaks up the causal factors into higher and lower-level tiers, facilitating the design of a tractable experimental plan.

The causality tree condenses the estimation of the effectiveness of SPD-HARM/Q-WARN to three primary causal factors:

i. The guidance given,
ii. The response to the guidance by the connected vehicles, and
iii. The response to the conditions that generated the guidance by vehicles obtaining their information from non-connected sources (including seeing other drivers in front of them slowing down).

Thus the Tier 1 test would be of these three primary factors: implemented at varying intensity levels (i.e. low, medium, high). Supplementary investigations and tests would then be conducted of the lower tier factors to understand how they come together to achieve a particular intensity level of one of the top tier factors.



Source: Kittelson & Associates/USDOT

Figure 4: Flow chart. SPD-HARM/Q-WARN effectiveness causality tree.

Notes to Source: Kittelson & Associates/USDOT
Figure 4:

- V2X is used in this chart as shorthand for a "connected vehicle" with some kind of device within it (besides the usual AM/FM radio) for receiving messages and communicating them (orally or visually) to the driver. The messages may come straight from the TMC via cellular phone, dedicated short range communications (DSRC), (collectively V2I) as well as directly from another vehicle (V2V).
- CMS is changeable message signs.
- 511 syst. is shorthand for a pre-trip internet accessible and/or an en-route cell phone accessible traveler information and route guidance service. It can be through a private sector or public sector provider.
- Radio includes commercial radio traffic reports, news alerts, and highway advisory radio (HAR), all accessible via the vehicles' AM/FM radio.
- In-vehicle technology (In-Veh. Tech.) includes collision avoidance radar (CAR) and adaptive cruise control (ACC).

- "Follow the leader" is where otherwise uninformed drivers notice several informed vehicles doing the same thing (e.g. slowing down, changing lanes, exiting the facility) and the uninformed driver chooses to follow these leaders.

This approach reduces the problem to 3 dimensions and if 3 intensity levels are selected for each dimension (high, medium, low), then the question of under what conditions are SPD-HARM and Q-WARN most effective can be answered in 9 tests of SPD-HARM alone, 9 tests of Q-WARN alone, and 9 tests of both applications together, for a total of 27 tests.

Note that as explained in Chapter 3, each test may consist of several subtests of different operating conditions (e.g., recurrent congestion, incidents, weather).

In addition, given the amount of resources and time that will be needed to answer this question (1b) it is advisable that these tests do double duty, answering several other questions at a time.

Question 1c Under what conditions is one application superior to the other?

This question can be answered by evaluating the test results for question 1b (the tests will be performed of each application separately).

QUESTION 2: WHICH COMMUNICATION METHOD IS BEST FOR NOMADIC DEVICES?

This question set consists of:

- (2a) Will a nomadic device that is capable of communicating via both DSRC as well as cellular meet the needs of the two applications?
- (2b) When is DSRC needed and when will cellular suffice?

Dedicated short range communication (DSRC) devices have low communication latencies and limited range (the specification for DSRC is a 300 meters - approximately 1,000 feet - range, but can be greater under favorable conditions). Cellular phone network has a much broader coverage range, but communications may be delayed (increased latency) under heavy cell traffic conditions.

The two questions lend themselves to the hypothesis that:

- Nomadic devices and the facilities may need to be DSRC capable under certain conditions.

The Impact Assessment can provide information to help address these questions (without specifically answering the questions) through sensitivity testing of different communication latencies (delays in delivery of messages between the connected vehicles and the infrastructure). The assessment will not be able to identify the specific environmental conditions when one method of communication is superior to the other, but it will be able to identify the impacts of communication latencies on the performance of the prototype.

QUESTION 3: WHAT ARE THE IMPACTS OF NEAR, MID, AND LONG TERM DEPLOYMENT?

The full text of the question is: “What are the impacts of future operational deployments of speed harmonization and queue warning applications in the near, mid, and long term?” The focus of this question is on the specific facility where the INFLO applications are tested by the PD contractor.

The hypotheses here are that:

- The performance of the prototype will improve as more drivers opt to be connected (market penetration).
- Consequently, the benefits of deployment will be different in the near, mid, and long-term.

The answer to this question and these hypotheses can be obtained by extrapolating the results of the Question 1b tests to near term, mid-term, and long term deployment, with an associated assumption of the market penetration for each deployment term. We propose to employ the following definitions regarding the time frame:

- “near term” implies deployment before 2020,
- “mid-term” is 2020 to 2030, and
- “long term” is post 2030.

QUESTION 4: WHAT LEVEL OF MARKET PENETRATION IS REQUIRED?

The question is: “At what levels of market penetration of connected vehicle technology do speed harmonization and queue warning applications become effective?”

The answer to this question will be produced through examination of the Question 1b test results. It is our hypothesis that:

Market penetration, communications delay (or loss),[11] and compliance rate are all tied together into the estimation of the overall driver response to connected vehicle (V2V and V2I) guidance (see Source: Kittelson & Associates/USDOT

- Figure 5).

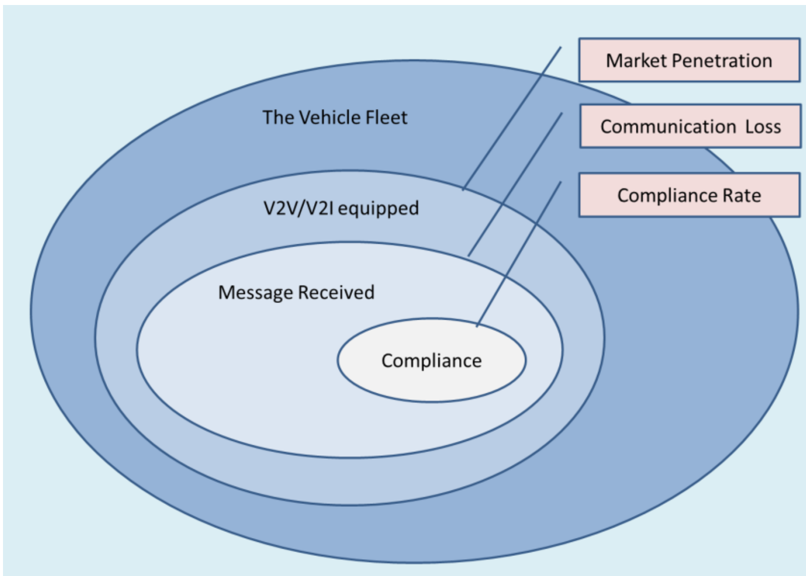
Market penetration determines who is eligible to receive the guidance. Communications errors, delays, and loss determine who among the eligible receivers get the message by when. Compliance rate (which will be a function of external conditions and the message received) then determines the actual responses of the drivers. At the same time, we must take into account that drivers may receive the message from multiple non-connected vehicle sources (their direct perception of the problem, changeable message signs, commercial radio, highway advisory radio or a traveler information system). In this case traveler information system (TIS) includes public

[11] Note that messages without a confirmation receipt are repeated until the confirmation is obtained. Thus, communication losses may translate into delays in transmission (latency) rather than actual lost messages. Losses occur, if the message does not arrive by a critical time point for action.

and proprietary area-wide traffic information systems that the driver may already subscribe to in their vehicle.

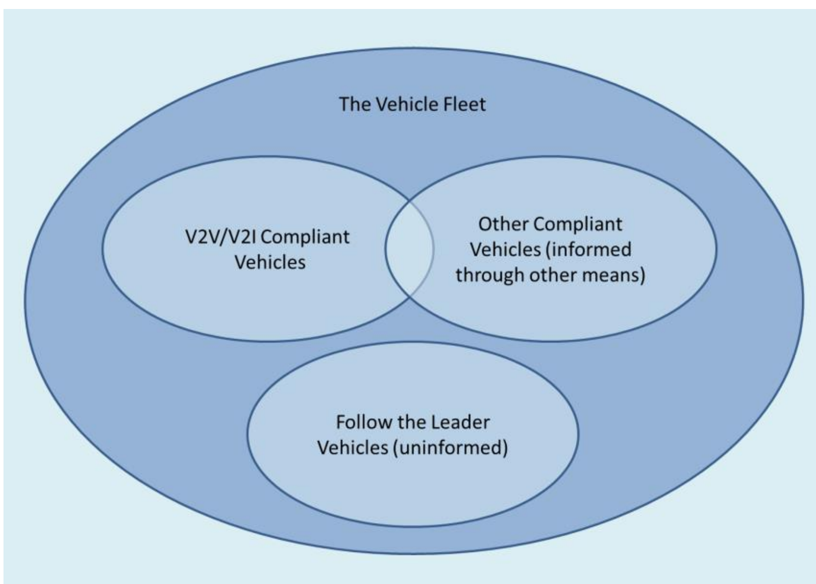
This assessment though, also needs to take into account the additive effect of other drivers receiving information from unconnected vehicle sources. In addition, there will be an additive effect where uninformed drivers seeing vehicles in front of them slow down, change lanes, or exit early, may do the same thing because they think the other drivers know what they are doing (see Source: Kittelson & Associates/USDOT

Figure 6).



Source: Kittelson & Associates/USDOT

Figure 5: Illustration. Market penetration, communication loss, compliance rate effect on response.



Source: Kittelson & Associates/USDOT

Figure 6: Illustration. Additive effects of other information sources and "Follow the Leader" effect.

QUESTION 5: WHAT ARE THE EFFECTS OF COMMUNICATION ERRORS AND LATENCY?

This question set consists of the following questions:

- (5a) How effective are the two applications when there are errors or loss in communication?
- (5b) What are the impacts of communication latency on benefits?

The working hypothesis is:

- Communication errors, losses, and latency all will reduce the effectiveness of SPD-HARM and Q-WARN. Some reduction in effectiveness may be acceptable.

The answers to this hypothesis and the two questions will require development of an understanding of the relationship between effectiveness and communication errors and latency.

Developing these relationships involves communication modeling which depends on the particular communication technology employed by the prototype.

One thought is that errors and loss of communication may be modelable in a simulation model as the simulation model equivalent of random, transient reductions in market penetration rate.[12] This presumes that errors implied by the question are "loss of direction or loss of information", not "misinformation" or "misdirection". Communication latency and errors can be modeled by communication simulation software like NS2/3, Qualnet, OMNET++ etc.[13]

Our proposed approach to answering this question set is to examine the question 1b test results which tested different levels of V2X compliance. Based on these results we will perform a sub investigation of how different levels of communications loss, errors, and latency would affect V2X compliance. We would then identify which combinations of market penetration, communications loss/latency and compliance rate are required to achieve a given V2X compliance.

Figure 7 shows a two-dimensional display of how we proposed to compute the overall response rate. The V2X compliance rate is depreciated by the communications loss rate (result shown in the y-axis). The depreciated compliance rate is multiplied by the market penetration rate to obtain the overall vehicle fleet response rate. The overall vehicle fleet response rate is then augmented

[12] As noted earlier, failure to obtain message receipt confirmation will result in re-transmission of message until it is acknowledged or until some set time limit expires. Thus communication loss may increase latency, rather than reduce information.

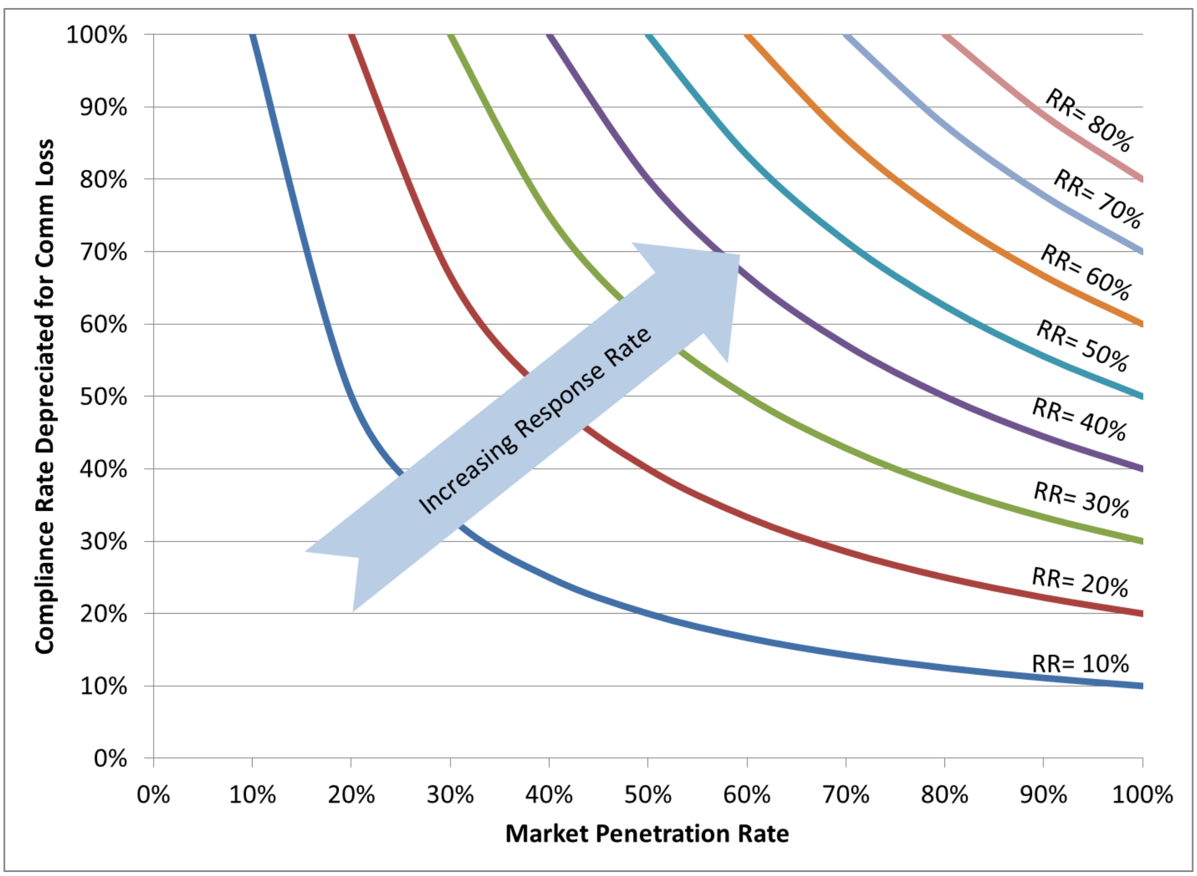
[13] H. Michael Zhang, U.C. Davis

to account for vehicles receiving the information from alternative sources and to account for "follow the leader" effects on uninformed drivers in the vehicle stream.

At this point, we envision this as a numerical exercise, no additional simulation runs required. One simply multiplies the market penetration rate by the percentage receiving timely communications by the percentage compliance to obtain the overall V2X compliance. As one factor goes up, the others must come down in order to preserve the same overall compliance.

In this approach, latency is treated as an "either/or" problem. Either the message gets through in time, or it does not. If it does not, then it is treated the same as a communication loss. Obviously it is possible for the message to come through in time, but it slows down the process. We propose to work backwards on this. We determine the minimum time needed by the process and as long as the message makes it through before that deadline, it is considered successful. We recognize that this misses some of the subtleties (such as slow transmittal times may prevent some more sophisticated decision making, while still allowing some simpler decisions), but given the magnitude and variety of questions to be addressed in this impact assessment, this is considered a minor sacrifice.

In this approach, misinformation or erroneous information is treated the same as a communication loss. Again, this sacrifices some of the nuances, but this is considered a minor sacrifice.



RR = overall response rate. Comm = Communication;

*Depreciated Compliance Rate = Compliance Rate * (1- Communication Loss Rate)*

Source: Kittelson & Associates/USDOT

Figure 7: Graph. Computation of effect of communication loss on overall response rate.

QUESTION 6: WHAT ARE THE BENEFITS OF WIDESPREAD RSE DEPLOYMENT?

This question set consists of the following questions:

- (6a) What are the benefits of widespread roadside equipment (RSE) deployment versus ubiquitous cell coverage?
- (6b) Which is more beneficial?
- (6c) What is the marginal benefit with data from existing sensors?

Roadside equipment (RSE) is installed to monitor conditions; collecting traffic flow, density, and speed data and transmitting it to a data environment (which in turn is accessible by connected vehicles and the transportation management center). Connected vehicles may access the data environment via Dedicated Short Range Communications (DSRC) devices or via the cellular telephone network.

The working hypotheses in this case are:

- Roadside equipment (RSE) and cell phone coverage each have their unique detection benefits for SPD-HARM and Q-WARN, which may vary under certain conditions.
- Widespread RSE detection may be a partial substitute for connected vehicle detection of speeds and headways.
- Existing sensors may provide benefits to SPD-HARM and Q-WARN implementation.

These questions and hypotheses can be addressed in the Question 1b tests by investigating how different mixes of roadside equipment affect:

- The ability to detect queues on the facility, and
- The ability to accurately predict congestion and queuing.

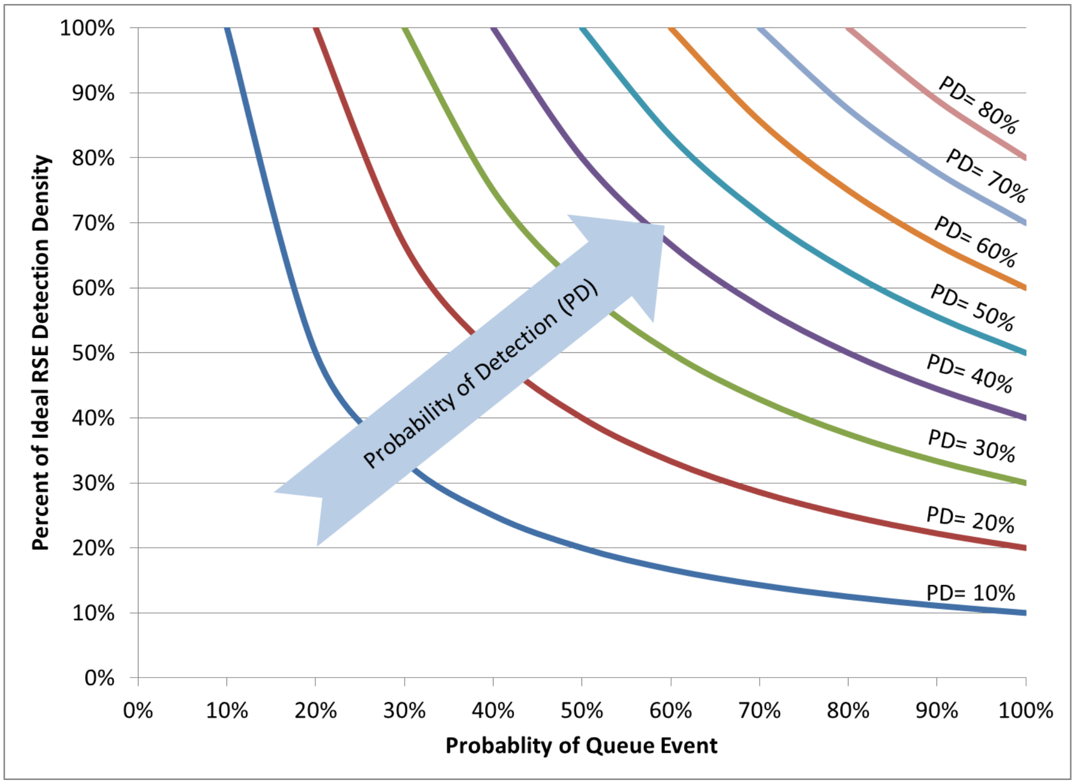
This would involve an examination of the lower tier effects:

- How RSE affects the ability to detect queues or safety hazards (caused by incidents, weather or recurring congestion) (which affects the top tier factor of “Guidance Given”)

At this point in time the thinking is that this examination is best performed as a probability analysis applied to the Question 1b Tier 1 test results. The probabilities of the top tier Guidance Given and Unconnected Vehicle Response are modified in light of the examination. The modified probabilities are used to discount the benefits reported in the Question 1b Tier 1 results. The modified performance results are compared to the original performance results to obtain the estimated effect of a given level of RSE deployment. The examination would run the spectrum of potential RSE deployment, from 0% RSE deployment, to detection deployment only, up to 1/3 mile spacing of detectors and changeable message signs.

Source: Kittelson & Associates/USDOT

Figure 8 illustrates how the probability of detection would be computed as a function of the ideal RSE detection density and the probability of queue event occurrence. A similar computation would be performed to estimate the probability of unconnected vehicles being informed of a queue event through other sources such as changeable message signs. The density of CMS would affect the probability of the drivers being informed of the event.



Source: Kittelson & Associates/USDOT

Figure 8: Graph. Probability of detection as function of rse density and event probability.

QUESTION 7: IS CONNECTED VEHICLE DATA REQUIRED FOR SUCCESS?

This question set consists of the following questions:

- (7a) To what extent are connected vehicle data instrumental to realizing a near-term implementation of the two applications?
- (7b) What are the impacts of dispersed vs. focused deployment of connected vehicles (i.e., nomadic devices)?

Working hypotheses include:

- V2X increases the effectiveness of SPD-HARM and Q-WARN when compared to a roadside equipment (RSE) only installation for monitoring conditions.

- A high market penetration of connected vehicles on one facility is more effective than half the penetration rate spread across two facilities. The single facility benefits are greater than the sum of the benefits of deploying the same number of connected vehicles across two facilities.

While a portion of the potential capabilities of SPD-HARM and Q-WARN can indeed be implemented near term without connected vehicles and connected vehicle data, this may not be a desirable outcome, because connected vehicles and connected vehicle data might be able to improve the effectiveness of SPD-HARM and Q-WARN. This then becomes a multi-dimensional question where different degrees of connected vehicle implementations (including consideration of market penetration) are considered along with different SPD-HARM and Q-WARN strategies, in combination with various roadside equipment (RSE) implementations. The effectiveness at achieving the INFLO performance objectives is then evaluated for each possible combination.

This question can be addressed by examining the results of the Question 1b tests and examining how increasing concentrations of connected vehicles improved the V2V response to the SPD-HARM and Q-WARN guidance.

$$P(V2VR) = MPR * (1 - CL) * RR \qquad \text{Equation 1}$$

Where:

P(V2VR) = percent of total vehicles responding to the V2X guidance

MPR = market penetration rate of V2X equipped vehicles

CL = percent of V2V communications lost.

RR = response rate for vehicles receiving the guidance.

The Question 1b tests evaluated three different levels of the percent of total vehicles responding to the V2X guidance. These percentages are then decomposed into their equivalent market penetration rates using Equation 1 and assuming a fixed response rate and a fixed communications loss rate. Question #7 is then answered by examining the Question 1b results in light of the computed equivalent market penetration rates.

CONCLUSIONS

The impact assessment of the SPD-HARM with Q-WARN prototype has to address several questions identified in the Task Order Proposal Request (TOPR) related to its effectiveness, data/communication technologies, user acceptance and deployment potential. **Error! Reference ource not found.Error! Reference source not found.** provides a list of the recommended tests to be conducted to answer the questions identified in the TOPR.

Error! Reference source not found. cross references the tests to the original TOPR questions.

Table 4: Experimental plan.

Test	Objective	Method	MOE's
1	Determine if SPD-HARM and Q-WARN bundles are more effective combined then individually	Examine numerically the Test #2 results.	Same as Test #2
2	Under what operational conditions are the applications most beneficial?	IA contractor to design and conduct a multi-dimensional simulation test program.	See in Performance Measures and Targets
3	When is DSRC needed and when will cellular suffice?	Examine Test #2 results to obtain sensitivity to different communication latencies	Same as Test #2.
4	Determine impacts of near, mid, long term deployment.	Examine numerically the Test #2 market penetration results.	Same as Test #2.
5	Determine required level of market penetration	Examine numerically the Test #2 market penetration results.	Same as Test #2.
6	Determine effects of communications errors and latency	Examine numerically the Test #2 results for latency and communication errors.	Same as Test #2.
7	Determine benefits of widespread RSE	Examine numerically the Test #2 results. Consider Test #3 conclusions.	Same as Test #2.
8	Determine extent to which V2X is required	Examine numerically the Test #2 results. Consider Test #3 conclusions.	Same as Test #2.

Table 5: Relation of tests to TOPR questions.

Test	Objective	TOPR Question
1	Determine if SPD-HARM and Q-WARN bundles are more effective combined then individually	#1a, 1c
2	Determine under what operational conditions the applications are most beneficial	#1b, 1c
3	When is DSRC needed and when will cellular suffice?	#2a, 2b
4	Determine impacts of near, mid, long term deployment.	#3
5	Determine required level of market penetration	#4
6	Determine effects of communications errors and latency	#5
7	Determine benefits of widespread RSE	#6
8	Determine extent to which V2V and V2I are required	#7

Hypotheses to Be Tested

The hypotheses identified in **Error! Reference source not found.** will be tested.

Table 6: Hypotheses to be tested.

TOPR Question	Hypothesis to be Tested
1	• SPD-HARM and Q-WARN will individually produce benefits even when implemented solo, without the other application. • SPD-HARM and Q-WARN will produce higher benefits when deployed in combination • There are some operational conditions under which SPD-HARM and Q-WARN are most effective and these conditions might vary depending on whether each application is implemented solo or in combination.
2	• Nomadic devices and the facilities may need to be DSRC capable under certain conditions.
3	• The performance of the prototype will improve as more drivers opt to be connected (market penetration). • Consequently, the benefits of deployment will be different in the near, mid, and long-term.
4	• Market penetration, communications loss, and compliance rate are all tied together into the estimation of the overall driver response to V2X guidance
5	• Communication errors, losses, and latency all will reduce the effectiveness of SPD-HARM and Q-WARN.
6	• Roadside equipment (RSE) and cell phone coverage each have their unique benefits for SPD-HARM and Q-WARN, which may vary under certain conditions. • Widespread RSE may be a partial substitute for connected vehicle detection. • Existing sensors may provide benefits to SPD-HARM and Q-WARN implementation.
7	• V2X increases the effectiveness of SPD-HARM and Q-WARN when compared to an RSE only installation. • A high market penetration of connected vehicles on one facility is more effective than half the penetration rate spread across two facilities. The single facility benefits are greater than the sum of the benefits of deploying the same number of connected vehicles across two facilities.

Hypotheses to be Tested in Controlled Environment Test or Small Scale Deployment

The microsimulation analysis will provide the bulk of the information used to test the hypotheses identified in Table 6. The small scale deployment will provide information for setting some of the parameters to be used in the microsimulation analysis. The controlled environment test will provide basic information on the technical operation of the prototype (generally, communication latencies).

CHAPTER 4. EXPERIMENTAL PLAN

This Chapter describes the processes for estimating or simulating the impacts of the prototype demonstration/test. The simulation of the prototype involves several steps described below including selecting the test bed, emulation software for simulation of the prototype, and operating scenarios to be tested.

Tests #1, 3, 4, 5, 6, 7, 8 all involve examination and extrapolation of Test #2 results. This Chapter thus focusses in detail on the design of Experiment #2 with brief descriptions of how the results of Experiment #2 will be extended to the other experiments.

OVERALL APPROACH TO EXPERIMENT #2

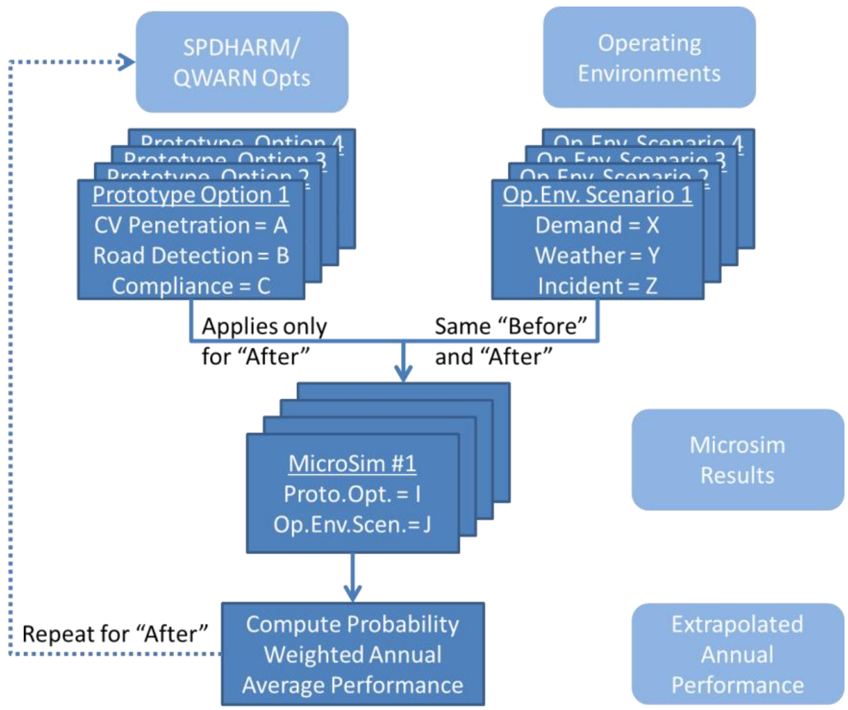
Experiment #2 will assess the effects of the SPD-HARM and Q-WARN applications using a "before and after" analysis approach. The performance measures for the selected test bed will be computed "before" application of the SPD-HARM and Q-WARN prototypes. The same measures will then be computed for the same test bed "after" application of the prototypes.

Since the effects of the prototypes are expected to vary according to the operating environment (high or low demand conditions, incident or non-incident conditions, and good or bad weather conditions) a set of operating environments (called scenarios) will be set up for testing the SPD-HARM and Q-WARN applications.

The SPD-HARM and Q-WARN applications however are also expected to affect the frequencies of occurrence for the scenarios. Both applications should reduce the frequency of incidents under high and low demand conditions, and under good and bad weather conditions. Thus, to arrive at a comprehensive estimate of the performance effects of the applications it is necessary to consider how SPD-HARM and Q-WARN change the probabilities of a facility operating in each operating condition (scenario). Thus a reliability analysis will be required to determine the effects of SPD-HARM and Q-WARN.

Source: Kittelson & Associates/USDOT

Figure 9 provides an overview of the process for Experiment #2.



Source: Kittelson & Associates/USDOT

Figure 9: Flow chart. Overview of Experiment #2.

PURPOSE AND SCOPE OF EXPERIMENT #2

The purpose of Experiment #2 is to identify under what operational conditions are the SPD-HARM and Q-WARN applications (together or separately) the most beneficial?

The experiment will focus on how the guidance given, the connected vehicle response, and the actions of unconnected vehicles will affect facility performance. The effects of the factors contributing to the responses of connected and unconnected vehicles (for example market penetration and dynamic message sign density) will be examined in other tests conducted outside of Experiment #2, but building on the information gained from Experiment #2.

Simulation Test Bed Selection

The test bed selection and the criteria upon which the selection was based are described in Appendix A. The result of this evaluation was that the 10-mile long San Mateo, California, US 101 freeway test site was selected for conducting the microsimulation impact assessment of the SPD-HARM/Q-WARN prototype. The 10-mile study area fully captures the usual geographic extent of the recurring queues at the test site.

Software for Emulating SPD-HARM and Q-WARN Prototype

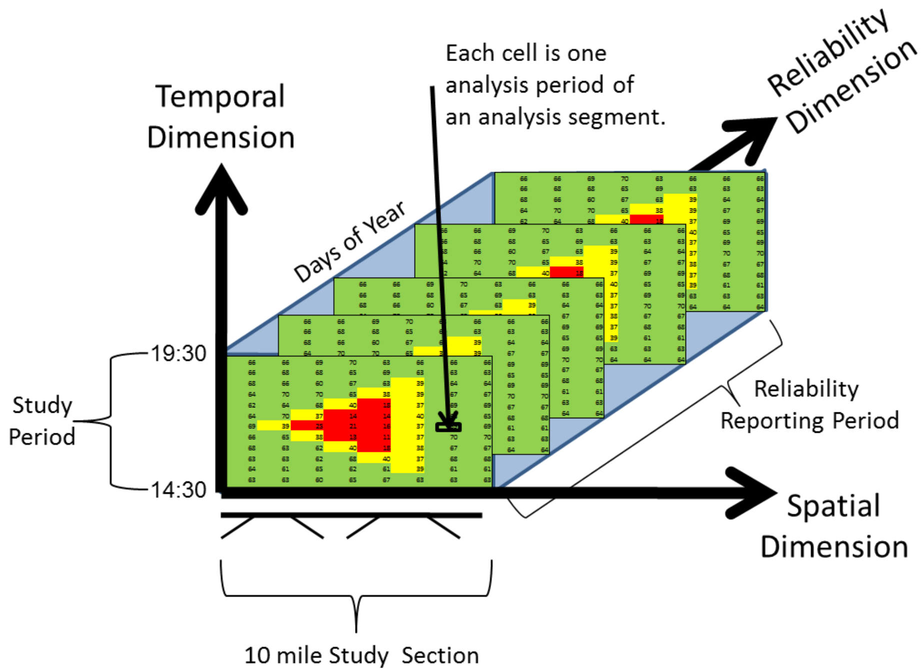
The impact assessment requires that a microsimulation software compatible emulator be constructed of the SPD-HARM/Q-WARN prototype. Appendix A discusses the identification and selection of a software emulator for the prototype. The result of this evaluation was that the ITRE

V2X connected vehicle emulator was selected for customization to better match the SPD-HARM/Q-WARN prototype. Appendix B describes the specifications for the functionality of the emulator.

Selected Study and Reliabilty Reporting Periods

To capture some of the effects of SPD-HARM and Q-WARN on incident frequencies a reliability analysis will be required. Reliability analyses, which involve prediction of changes in incident frequencies need to consider an extended time period for the reliability analysis, on the order of one year (5 years is usually preferred to detect changes in the field in collision rates, but since we will be performing the analysis in a simulation environment, analysis of a single year with the results extrapolated to 5 years should be sufficient) See Source: Kittelson & Associates/USDOT

Figure 10 for terms used.



Source: Kittelson & Associates/USDOT

Figure 10: Illustration. Reliability analysis terminology.

Reliability analyses are very demanding on resources, so in order to conserve study resources, days and hours of the year when demand is low and the effects of SPD-HARM and Q-WARN are likely to be negligible, will be neglected. Thus the selected reliability reporting period for the analysis of Experiment #2 results will be approximately 250 non-holiday weekday peak periods of a single year.

To further conserve study resources, the focus of Experiment #2 (The Study Period) will be on the PM peak period, under the assumption that AM peak period benefits would be similar for the facility.

The duration of the PM peak period selected for analysis will be the 5-hour peak from 2:30 PM to 7:30 PM. Recurring congestion usually begins around 3:00 PM and ends by 7:00 PM on the selected test site.

OPERATING ENVIRONMENT SCENARIOS FOR EXPERIMENT #2

In the simulation study, we will evaluate the impacts of the SPD-HARM and Q-WARN algorithms in isolation and in combination on facility performance for the following operating scenarios identified in the INFLO ConOps:

- Fixed-point breakdown: This relates to recurrent congestion, i.e., presence of fixed bottleneck(s) along the test facility that create queues upstream which in turn is a function of variations in demand. The facility will be simulated before, during and after the bottleneck activation. The impact depends on the severity of congestion, i.e., the level of traffic demand.
- Non -fixed point (incident caused) breakdown: This involves the modeling of incident conditions. The impact depends on the incident severity and duration, and prevailing operating conditions on the facility. We consider two levels of incident severity: 1-lane blocking incident lasting 30 minutes and 60 minutes.
- Weather related breakdown: Inclement weather affects both the speeds and discharge flows along a highway facility that may trigger congestion and formation of shock waves. The impacts depend on the intensity of weather conditions. The weather options for the prototype include three levels of pavement condition (dry, wet, icy/snowy) and two levels of visibility (good, poor).

Error! Reference source not found. shows the combinations of three factors into operating nvironment scenarios for microsimulation analysis in Experiment #2. The objective is simulate a sufficient variety of probably scenarios so as to be able to estimate the full year performance of the facility under “before” and “after” SPD-HARM and Q-WARN conditions.

Demand levels are set at representative points on the peak period demand distribution for the facility where congestion effects are likely to produce results relevant for testing of SPD-HARM and Q-WARN (the 25th percentile, the 50th percentile, and the 95th percentile highest demand for the year).

There are an infinite number of potential incident locations, types, starting times, and durations possible for the facility. In this experiment a few representative incidents are selected for microsimulation. While severe incidents can have severe effects, there probabilities are usually so low that they are unlikely to significantly affect the Full Year performance of the facility with or without SPD-HARM and Q-WARN. Consequently two comparatively frequent incident types are selected, each involving closure of one lane of travel, but one for 30 minutes duration and the other for 60 minutes duration. Non-lane closure incidents are the most frequent, but their capacity effects are minor, so they will not be simulated. Finally, the starting times and locations of the incidents will be selected for microsimulation purposes to be generally early in the study period and comparatively far downstream in the facility (so that the microsimulation model has the best opportunity for tracking the full congestion impacts of each incident type).

The weather types are as defined in

, Appendix B. There are 6 potential weather types combining 3 pavement condition subtypes and 2 visibility subtypes. Two of these have been selected for modeling at this test site based on their relative frequencies. When extrapolating the results to other parts of the country, post-processing will be applied to extend the results to additional weather types that may be more frequent in other parts of the country.

Table 7: Operating environment scenarios for Experiment #2.

Op. Env. Scenario	Demand	Incident Type	Weather Type	Probability
1	25^{th}% (Low)	None	Dry Pavement, Good Visibility	TBD
2	50^{th}% (Median)	None	Dry Pavement, Good Visibility	TBD
3	95^{th}% (Extreme)	None	Dry Pavement, Good Visibility	TBD
4	25^{th}% (Low)	1 Ln – 30 min	Dry Pavement, Good Visibility	TBD
5	50^{th}% (Median)	1 Ln – 30 min	Dry Pavement, Good Visibility	TBD
6	95^{th}% (Extreme)	1 Ln – 30 min	Dry Pavement, Good Visibility	TBD
7	25^{th}% (Low)	1 Ln – 60 min	Dry Pavement, Good Visibility	TBD
8	50^{th}% (Median)	1 Ln – 60 min	Dry Pavement, Good Visibility	TBD
9	95^{th}% (Extreme)	1 Ln – 60 min	Dry Pavement, Good Visibility	TBD
10	25^{th}% (Low)	None	Wet Pavement, Good Visibility	TBD
11	50^{th}% (Median)	None	Wet Pavement, Good Visibility	TBD
12	95^{th}% (Extreme)	None	Wet Pavement, Good Visibility	TBD
13	25^{th}% (Low)	1 Ln – 30 min	Wet Pavement, Good Visibility	TBD
14	50^{th}% (Median)	1 Ln – 30 min	Wet Pavement, Good Visibility	TBD
15	95^{th}% (Extreme)	1 Ln – 30 min	Wet Pavement, Good Visibility	TBD
16	25^{th}% (Low)	1 Ln – 60 min	Wet Pavement, Good Visibility	TBD
17	50^{th}% (Median)	1 Ln – 60 min	Wet Pavement, Good Visibility	TBD
18	95^{th}% (Extreme)	1 Ln – 60 min	Wet Pavement, Good Visibility	TBD

Notes: TBD = to be determined. 1 Ln – 3 min = one lane closed for 30 minutes.

The probability of each scenario occurring during the PM peak period over the course of year of non-holiday weekdays will be determined by examining the incident and weather logs, and demand profile for the test site.

As part of the post processing of the Experiment #2 simulation results to obtain annual average (Full Year) performance results, an initial set of incident, weather, and demand level probabilities will be used for the test site based on actual real-world logs for the test site.

The results will then be examined (by testing the effects of different probabilities on the Full Year results) to determine:

- How more frequent severe incidents might affect the predicted Full Year performance benefits of SPD-HARM and Q-WARN?
- How more frequent more extreme weather effects (e.g. poor visibility, icy/snow conditions) might affect the predicted Full Year results.

- At what levels of incident and weather frequencies might the predicted benefits of SPD-HARM and Q-WARN tip from positive to negative.

Operating environment scenarios with exceptionally low probabilities (the value to be determined through test computations, but generally those falling under one hundredth of one percent) will not be formally microsimulated since their results would not significantly affect the computed Full Year performance of the facility with or without SPD-HARM and Q-WARN.

SPD-HARM/Q-WARN PROTOTYPE OPTIONS

The SPD-HARM and Q-WARN prototype options to be tested in Experiment 2 include:

- Evaluation of the impacts of SPD-HARM and Q-WARN implementations separately or in combination.
- The impacts of different user selected values for the user definable parameters in the two applications.
- The impacts of different densities of road sensors and dynamic message signs.
- The impacts of different market penetration rates.

Evaluation of SPD-HARM and Q-WARN in Combination or Separately

The current prototype for Q-WARN involves detection and delivery of a queue warning message to connected vehicles and dynamic message signs (if available) to vehicles a user specified number of miles upstream. The message will state the time or distance to the back of queue.

For either application (SPD-HARM or Q-WARN), detection will operate similarly (a combination of road detectors and connected vehicle detection).

Presumably the driver receiving a Q-WARN message but no SPD-HARM message will slow down as the time or distance to the queue approaches zero.[14] This action, on the part of a compliant driver, would be similar as would occur with SPD-HARM in operation, although the driver might pick different speeds upstream of the queue in the absence of SPD-HARM.

Given the similarities, it would be cost inefficient to separately microsimulate SPD-HARM and Q-WARN individually. Two sets of simulation runs can be made, one set for the “before” condition with no SPD-HARM or Q-WARN and one set for the “after” condition, with both SPD-HARM and Q-WARN operating together. The effect of applying SPD-HARM and Q-WARN separately can then be teased out of the simulation runs by examining the proportions of events where one or the other application would not be operational, and allocate the simulated results for the combined applications to each one separately.

This approach will cut the number of microsimulation runs that must be processed in half (from 4 sets to 2 sets).

[14] The small scale demo by the PD contractor might provide some insight into driver reactions, but the sample size will be limited to 25 people and will be skewed towards paid college age drivers.

Effects of User Definable Parameters

The user definable parameters for the SPD-HARM and Q-WARN prototypes along with their recommended values for Experiment #2 are listed in

.

They generally give the user the flexibility to define the queue state for the facility and to fine tune the sensitivity of the SPD-HARM and Q-WARN applications so as to minimize “false alarms” by the system.

For the purposes of Experiment #2, side tests will be performed to determine reasonably effective values of these user definable parameters for use in the experiment. Different false detection rates will be assumed for the lane detectors and the connected vehicles and the appropriate minimum number and percent of detectors and connected vehicles determined that provide sufficient valid detections (power of the test) while minimizing false alarms (Type I errors). These side tests will be primarily statistical analyses assuming an appropriate statistical distribution for the errors.

The “best values” for user definable parameters found in the side tests plus the values identified in Table 8 for the other user definable parameters will be used in the Experiment #2 tests.

Effects of Market Penetration and Road Infrastructure

The effects of different market penetration rates and road infrastructure densities of detection and changeable message signs will be determined in Experiment #2 using the specific values shown in Table 8.

The following market penetration rates will be tested in Experiment #2: none, 10%, 25%, and 50%. Connected vehicles will be assumed to have 0% communication loss, zero communication latency, and 100% compliance for the purposes of the microsimulation runs within Experiment #2. Following completion of the microsimulation model runs a graph of the performance with SPD-HARM and Q-WARN is constructed based on the results. Then the market penetration can depreciated for communication loss, latency, and less than 100% compliance to obtain the effects of those factors on performance.

The road detectors and changeable message signs will be tested at the following levels: none, half mile spacing, and one-mile spacing. Road detectors and changeable message signs will be assumed to operate without error or latency for the purposes of the microsimulation runs within Experiment #2. Charts will be constructed of how different road detector and message sign spacings affect performance. From this chart the results can be interpolated and depreciated to reflect different error rates.

A total of 4 levels of market penetration, 3 levels of road detector spacings, and 3 levels of changeable message sign spacings (a total of 36 possible combinations) will be potentially tested in Experiment #2.

Table 8: User definable parameters for SPD-HARM/Q-WARN prototype emulator.

USER DEFINABLE Q-WARN PARAMETERS	COMMENT
1. Average Speed Threshold for Queued State	Set at 5 mph for all tests
2. Min. Seconds below speed threshold before Lane detector is considered to be in "Queue"	Perform side tests to find best values under varying equipment error rates.
3. Criteria for Link in "Queue" state a. Number Lane Detectors in "Queue". b. Percent Lane Detectors in "Queue".	Perform side tests to find best values under varying equipment error rates.
4. Min. Seconds below speed threshold before connected vehicle is considered to be in "Queue"	Perform side tests to find best values under varying equipment error rates.
5. Criteria for SubLink in "Queue" state a. Number connected vehicles in "Queue". b. Percent connected vehicles in "Queue".	Perform side tests to find best values under varying equipment error rates.
6. Upstream broadcast range for queue warning	Set at 1 mile for all tests
USER DEFINABLE SPD-HARM PARAMETERS	**COMMENT**
7. Recommended speeds by visibility and pavement condition type	Set at values shown in of Appendix B
8. Criteria for Valid Link Speed determination: a. Number Lane Detectors in operation b. Percent Lane Detectors in operation.	Perform side tests to find best values under varying equipment error rates.
9. Criteria for Valid SubLink Speed determination: a. Number connected vehicles present with comm. b. Percent connected vehicles present with comm. c. Smoothing period (min.secs) for spd estimates.	Perform side tests to find best values under varying equipment error rates.
10. Speed range for determining troupes for SPD-HARM	Perform side tests to find best values under varying equipment error rates.
11. Maximum and Minimum speeds for SPD-HARM	Set at 70 mph and 25 mph for
MARKET PENETRATION AND INFRASTRUCTURE	**COMMENT**
12. Percent connected vehicles	Test range: none, 10%, 25%, 50%.
13. Road detector spacing	Test range: none, 0.5, 1.0 mile spacing
14. Changeable Message Sign spacing	Test range: none, 0.5, 1.0 mile spacing

MICROSIMULATION RUNS

To fully test all possible combinations of 18 operating environment scenarios and 36 possible levels of market penetration and infrastructure would require 18 x 36 or 648 microsimulation model runs (which in turn would be multiplied by 10 repetitions per run to obtain valid results). The number of model replications will be determined based on state-of-art/practice guidelines.[15]

[15] FHWA Analysis ToolBox, Vol. III, "Guidelines for the Application of Microsimulation Software,"

Not all of these combinations will prove to be interesting for various reasons (extremely low likelihood, miniscule effects, etc.).

Therefore we propose to perform some initial simulation runs to scope out the performance effects and determine if some combinations can be skipped if it looks like they will contribute little additional information to the assessment.

INCORPORATION OF OPTIONAL CONTROLLED ENVIRONMENT TEST RESULTS

To the extent that the PD Contractor optional controlled environment tests provide insights into the range of user definable parameters that optimize the performance of the SPD-HARM and Q-WARN applications, that information (if available early in the Impact Assessment process) will be used to bound the range of parameters evaluated, or (if available late in the Impact Assessment process) will be used to inform the Impact Assessment of the microsimulation model results.

INCORPORATION OF OPTIONAL SMALL SCALE DEMONSTRATION RESULTS

To the extent that the PD Contractor optional small scale demonstration tests provide insights into the range of user definable infrastructure and connected vehicle parameters that optimize the performance of the SPD-HARM and Q-WARN applications, that information (if available early in the Impact Assessment process) will be used to bound the range of parameters evaluated, or (if available late in the Impact Assessment process) will be used to inform the Impact Assessment of the microsimulation model results.

CHAPTER 5. DATA TO BE COLLECTED

If the PD Contractor is authorized to proceed with the optional small scale demonstration test, this chapter identifies the performance and explanatory data ("before" and "after") not generated within the prototype system that need to be collected, and the process by which the data will be collected.

The data consist of detector measurements of speed, occupancy and speed at each fixed detector location at the test site. We assume that the data for the selected small scale demonstration site are stored in a data archival system (e.g., PeMS in California) and are readily accessible. In addition, we may have data available from mobile sources regarding the traffic performance. Examples include INRIX speed data at 1-minute intervals upstream of an incident or a bottleneck location.

PROCESSES FOR VERIFYING DATA QUALITY

This section describes the processes for verifying data quality and for cleaning data, and minimum thresholds for data quality.

We assume that we will obtain the fixed detector data from the demonstration test site in their raw format of 20-to-30 seconds, resolution. We first check the loop detector data for faulty and missing values. The data cleaning techniques described in detail elsewhere[16] consist of a) checking raw 20 sec(30 sec) occupancy and count samples against thresholds, and/or b) computing the entropy of occupancy values over a specified time intervals. Filling of missing values can be done based on a linear model of neighboring detectors.

Next we will aggregate the data into 5-minute and 15-minute intervals. Five minute intervals will be used as input to the simulation model. 15 min resolution will be used to characterize operating conditions as in typical macroscopic analysis tools (e.g., HCM).

We will also verify the data provided to us from the PD contractor. We will design and execute data checks soon after we know the algorithms to be tested and the sample data collected during the controlled environment test

[16] Chen, C., et al, "Detecting Errors and Imputing Missing Data for Single Loop Surveillance Systems," Transportation Research Record #1855, Journal of the Transportation Research Board, 2003.

CHAPTER 6. GATHERING FEEDBACK

This section describes the methods for collecting feedback from stakeholders and demonstration/test drivers, processing and analyzing feedback, and integrating the results into the assessment of the impacts of the prototype as well as a large-scale deployment.

The test drivers in the optional small scale demonstration or the optional closed environment (test track) test should be asked the following questions after the test:

- Did they find that their driving experience was better or worse with the prototype? What did they like and dislike about the prototype?
- What do they think public acceptance would be of the device?
- Do they have any advice on how the prototype might be improved?

The stakeholders will be asked to review and comment on the microsimulation results as well as the optional small scale demonstration or optional closed environment test.

CHAPTER 7. COOPERATIVE FEATURES & EXPECTATIONS

This chapter describes the proposed sharing of data and the data expectations from the PD Contractor.

DATA TO BE SHARED ON THE RDE AND OSADP, AND PII DATA TO BE PROTECTED

This section identifies what data are intended to be broadly shared on the RDE and what data elements are proprietary or include personal identifiable information (PII).

The data that potentially would include personal identifiable information will be data collected as part of the prototype field small scale demonstration and cannot be determined at this stage. The research team is committed to share all the data from the simulation modeling assessment plus field data from surveillance systems.

We will make the impacts assessment methodology and supporting code (e.g., spreadsheet files, database queries, analytical tool input and output files,) and API(s) developed under this project, available as open source on OSADP (Open Source Applications Development Portal).

DATA EXPECTATIONS FROM PD CONTRACTOR

The success of certain aspects of the Impact Assessment Plan hinge on the data to be delivered by the PD Contractor and/or FHWA.

With respect to the PD Contractor's optional tasks (the Controlled Environment Test or the Small Scale Demonstration) the following data would improve the value of the impact assessment:

For the Controlled Environment Test Experimental Plan (if elected by FHWA)

- Connected Vehicle data
  - Second by second vehicle trajectory data for connected test vehicles.
  - Second by second SPD-HARM/Q-WARN message content and display status for each test vehicle (message logs for each vehicle).
- Algorithm Performance Data
  - Sensitivity tests of the effect on algorithm performance of different values of user definable parameters (Type I and Type II errors – false alarms and real queues undetected). This should include the effect of the parameters on the lag time between when a queue begins and when it is first detected.

For the Small Scale Demonstration Experimental Plan (if elected by FHWA)

- Infrastructure data
  - "Before and during demo" data on weather, incident logs, traffic speeds and volumes for each segment of the facility. The infrastructure is hopefully dense enough to compute average speeds and detect queues in the absence of

  - connected vehicles (so that the accuracy of using connected vehicles in-lieu of road detectors can be evaluated).
  - Message logs (message with time stamp) for changeable message signs (CMS).
- Connected Vehicle data
  - Second by second vehicle trajectory data for connected test vehicles.
  - Second by second SPD-HARM/Q-WARN message content and display status for each test vehicle (message logs for each vehicle).
- Algorithm Performance Data
  - Sensitivity tests of the user definable algorithm parameters selected for the tests.
  - Event detection and message logs for central processor showing time of detection, message selected, time of message dissemination, target vehicles and target CMS signs for message.
  - PD team's assessment of accuracy of event detection and message sent (rates of missed events, false alarms, incorrect message selection, etc.) under various user definable parameters and conditions.

APPENDIX A – SELECTION OF SIMULATION MODEL TEST SITE AND EMULATOR SOFTWARE

This appendix describes the selection of the recommended simulation model test site and the connected vehicle emulator software for testing the SPD-HARM/Q-WARN prototype.

SIMULATION TEST BED SELECTION

Criteria for Test Bed Selection

The requirements for selecting the test bed include:

- Freeway facilities that are between 5 and 10 miles long,
- The freeway facilities experience recurrent and non-recurrent congestion
- The freeway facilities are coded and calibrated into microscopic simulation models.
- The simulation model should include interchanges and/or signalized intersections at the foot of the ramps as well as the freeway mainline,

The focus on freeways is because they provide a more controlled environment for examining the benefits of SPD-HARM and Q-WARN, and are likely, because of the high speeds involved, to show the greatest benefit of SPD-HARM and Q-WARN.

The 5 to 10 mile length was selected to ensure adequate distance to adequately track and trap the benefits of SPD-HARM and Q-WARN without overburdening the Impact Assessment with analysis of exceptionally long facilities.

The presence and availability of a previously calibrated and validated commercial microsimulation model is vital for cost-effectively generating the MOE's under the varying conditions necessary to answer the questions posed in the TOPR for this Impact Assessment. In addition, the software used to operate the simulation model must be capable of interfacing with custom developed API's for emulating SPD-HARM and Q-WARN.

The presence of recurring and non-recurring congestion is necessary to be able to observe the benefits of SPD-HARM and Q-WARN.

Candidate Test Beds

Error! Reference source not found. lists the simulation test beds available to the research team. e did additional searches to identify simulation test beds that have been used in the analysis of SPD-HARM algorithms in recently completed and/or ongoing research. None additional were found that were readily available to the research team.

We reviewed the available testbeds listed in Table 9 seeking facilities with the presence of recurring bottlenecks, and the availability of real world detector coverage to obtain real-time data on operating conditions. The two sites that best met these and the previously described criteria were:

- I-210 in Southern California.
- US 101 in the San Francisco Bay Area, close to the California Test Bed for Connected Vehicles.

Both test sites have been coded and calibrated in the VISSIM model. The I-210 site has been used to evaluate alternative ramp metering strategies, and the US 101 site has been used to test alternative traffic management schemes.

Note that the US 101 site could be extended to include parallel arterial (El Camino Real) which is part of the California Test Bed if an arterial demonstration test were needed for future impact assessments.

Table 9: Available calibrated simulation model test sites.

Location	Facility	Limits	Miles	Peaks	Software
Freeways					
S. Clara Co, CA	US 101	Gilroy to San Jose	25.0	AM/PM	CORSIM
Alameda Co, CA	I-580	I-680 to I-205	20.0	AM/PM	Paramics
Raleigh, NC	I-40**	NC 147 to Gorman Street	16.0	PM	VISSIM
Philadelphia, PA	I-95	PA/Delaware to Schuylkill River	15.0	AM/PM	VISSIM
Milwaukee, WI	I-43/I-894	Loomis Rd to Greenfield Ave	7.0	PM	VISSIM
Berkeley, CA	I-80 WB	Carlson Blvd. to I-580	6.5	AM	VISSIM
Harford Co, MD	I-95	MD 543 to MD 152 (Mountain Rd)	6.0	AM/PM	Aimsun
Alameda Co, CA	I-880	SR 92 to Marina Blvd.	6.0	AM/PM	VISSIM
Pasadena, CA	I-210	Vernon to I-710	14.0	AM	Paramics
San Mateo, CA	SR 92	De Anza to Foster City Blvd.	5.2	AM/PM	VISSIM
St. Louis, MO	I-20	Dougherty Ferry Rd to Gravois Rd	4.8	PM	VISSIM
San Mateo, CA	US 101	Hillsdale to Mariner Island	4.7	AM/PM	VISSIM
St. Louis, MO	I-44	Marz Ln to Big Bend Rd	4.5	PM	VISSIM
Arterials					
Whistler, BC	Sea to Sky	Function Junction Stat. to Lorimer	5.5	PM	VISSIM
Waterloo, IA	University	SH 27 to Sargent Road	5.0	AM/PM	VISSIM
Broward Co, FL	SH 842	US 1 to US 44/SH7	4.0	AM/PM	VISSIM
Anthem, AZ	Daisy Mtn.	Galvin Pk to W. Anthem Wy	2.0	AM/PM	VISSIM/ASC
Networks					
Raleigh, NC	Research Triangle**	1000 links, 200 zones, 54 signals, 681 detectors	112.0 Ctr-Line	PM	Aimsun

SELECTED TEST BED – SAN MATEO US 101 FREEWAY

Following further review of the leading candidates, I-210 and US101/SR92, we propose the use of the US101/92 testbed to perform the impact assessment through simulation. Additional information is given below:

Background

The US-101 and SR-92 testbed modeled in VISSIM platform was developed in a project (2009-2013) funded by Metropolitan Transportation Commission (MTC), San Mateo County Transportation Authority and City and County Association of Governments of San Mateo County. The model year is 2010 and the simulation time period is from 2:30 PM to 7: 30 PM. The traffic modes modeled in this testbed consist of the passenger car and truck. This testbed had been fully calibrated based on observed traffic conditions in the field, such as volumes, travel time, bottleneck location and duration of congestion. MTC approved the calibrated and validated VISSIM model for the study in 2010/2011. A series of operational and traffic management improvements were analyzed including ramp metering, auxiliary lanes, lane expansions, ramp closures due to short weaving/diverging/merging, and multimodal travel information.

Testbed Characteristics

The original US-101/SR-92 testbed is shown in Source: Kittelson & Associates/USDOT

Figure 11. The testbed is located approximately 10 miles south of the San Francisco International Airport (SFO). The highlighted purple line in Source: Kittelson & Associates/USDOT

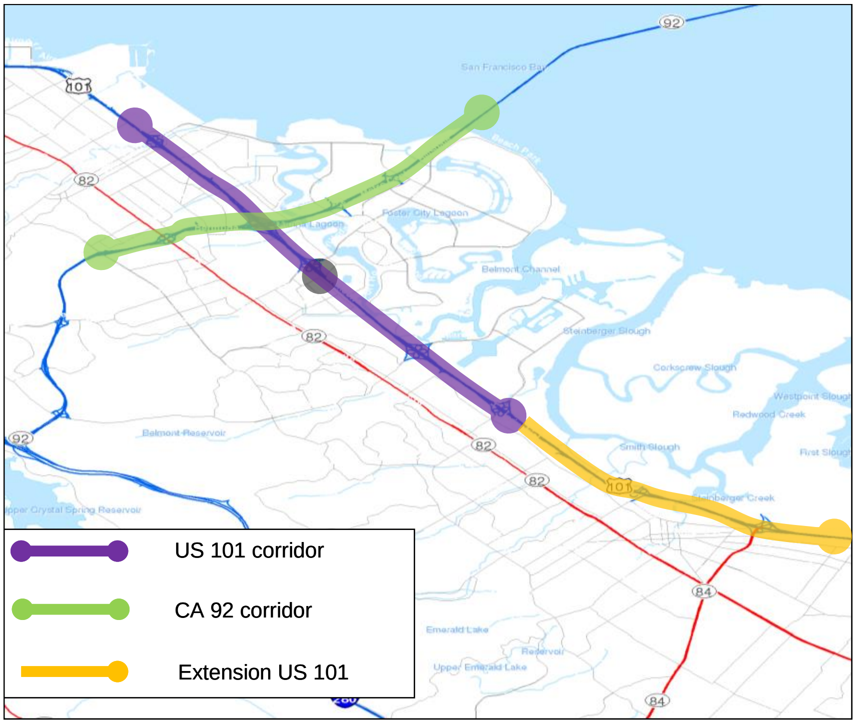
Figure 11 represents the limits of US-101 corridor as originally modeled; and the green line represents the limits of SR-92 corridor.

Traffic congestion in the network occurs in the northbound direction of US-101 northbound during the PM peak periods. Figure 12 also shows typical pm peak traffic conditions based on Google maps. These plots clearly show the presence of a bottleneck at the US-101 and SR-92 interchange, which is a recurring bottleneck during PM peak hour. Note that queues extend part the original US101/92 testbed boundary. Therefore, to properly analyze ATDM and/or DMA scenarios we extended the original network into VISSIM to capture the spatial and temporal effects of the congestion along US-101. The network extension along US101 is shown in Source: Kittelson & Associates/USDOT

Figure 11.

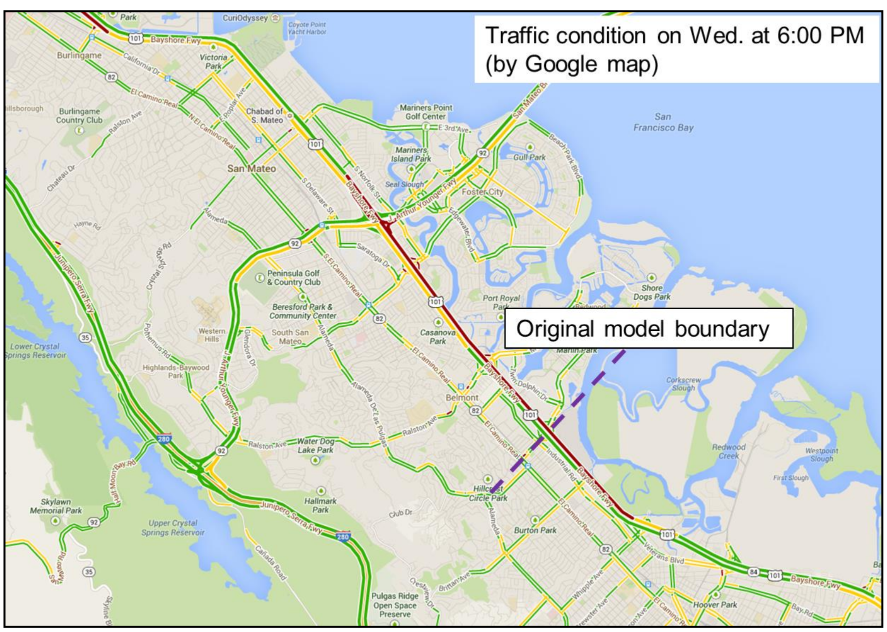
Since this US-101 and SR-92 network was modeled in the microscopic VISSIM simulator (version 5.40), the model can provide time-dependent performance measures, such as time-dependent volume, speed, travel time, delay, and queuing at different levels (individual vehicle, lane, link and subarea).

The built-in functions and Application Programming Interface (API) in VISSIM enable various strategies to be modeled in the testbed, including but not limited to: ramp metering, speed harmonization, queue warning, HOV/HOT lanes, variable lane use, shoulder lanes/reversible lanes, adaptive signal control, connected vehicles, etc. Moreover, the travelers' response can be modeled by adjusting their behavior based on user-defined threshold(s), decision rule(s), and dynamic network performance.



Source: Kittelson & Associates/USDOT

Figure 11: Illustration. San Mateo US-101 test site.



Source: Google Maps, https://maps.google.com/maps?hl=en&tab=wl, accessed January 29, 2014.

Figure 12: Illustration. Recurring traffic conditions on US 101 PM peak.

There are comprehensive data sources within the US-101 and SR-92 testbed area, which can be used for model inputs, model calibration and validation for future studies. Table 10 summarizes the data sources and the corresponding data.

Table 10: Available real world data within San Mateo US 101 test site.

Sources	Data
Loop Detector Data (PeMS system) Detector spacing: 0.4 mile Detectors located on each travel lane and ramps	Volumes, Speeds, Densities (Occupancies) at various time resolutions Travel times along links/route
Inrix	Travel time statistics
Workzones (locations and operational details)	Caltrans District 4
SFO Airport Station and Caltrans Database	Weather information
California Highway Patrol and Bay Area Freeway Service Patrol	Incidents CHP data readily available in the PeMS system
SamTrans, CalTrain	Transit information

SOFTWARE FOR EMULATING SPD-HARM AND Q-WARN PROTOTYPE

The prototype SPD-HARM with Q-WARN algorithms are being developed by the PD contractor. They are described in the Prototype Design Document produced by the PD contractor and delivered in draft form on January 15, 2014.[17]

Based on the Prototype Design Document the IA contractor has prepared specifications for a microsimulation software application program interface (API) to emulate the functionality of the PD Contractor's Prototype. These specifications for the SPD-HARM/Q-WARN Prototype Emulator API are presented in Appendix B.

The IA team has several APIs available for emulating vehicle-to-vehicle (V2V) and vehicle-to infrastructure (V2I) communications (see

[17] Kevin Balke, Hassan Charara, Srinivasa Sunkari; draft Report on Dynamic Speed Harmonization and Queue Warning Algorithm Design, Texas A&M Transportation Institute, FHWA, Washington, DC, January 15, 2014

Table 11). Based on review of these APIs and supporting documentation the University of Arizona “connected vehicle” API for the VISSIM model and the API for the AIMSUN model developed at ITRE North Carolina State University (Mei and Rouphail) appeared to be the most promising for adaptation (customization) as the SPD-HARM/Q-WARN Prototype Emulator API. They had the advantage of being created for VISSIM (the software for the selected test site model) or Aimsun, software for which conversion routines were readily available for conversion from VISSIM. Among the three available Aimsun connected vehicle API’s, the Mei/Rouphail API had the advantage of being most familiar to members of the IA contractor team.

Table 11: V2V and V2Is APIs available to the IA team.

Developer	Software	V2V and V2I Features Enabled
Yeo, Skabardonis	AIMSUN	Incident detection, incident alert
Shladover et al	AIMSUN	Variable Speed Limits, Cooperative Adaptive Cruise Control
Zhang et al	VGrid	Incident Detection, Variable Speed Limits, accident alert
UC Davis	VANET: JiST/SWANS	VGSim has been used by the authors to study incident detection on freeways and study vehicle rerouting and variable speed limits under the VANET environment. JiST/SWAN can simulate latency and interference and be used to develop/test communication protocols. VGSim uses DSRC/WAVE protocol.
Mei, Rouphail et al	AIMSUN	Dynamic Route Diversion, Variable Speed Limits**
University of Arizona	VISSIM and C++ components	Implemented equipped vehicles that broadcast Basic Safety Messages that contain GPS position data, speed, acceleration, status of braking system, etc…The external components can be a hardware of virtual OBE and a hardware of virtual RSE. OBE's can communication (sic) with each other or with the RSE. Vehicles can send other J2735 messages including Signal Request Message and can receive messages such as Signal Status Messages. Other messages are easy to add and the driver behavior can be modified to include change in speed, lane, etc. Will work with any network that is or can be modeled in VISSIM. The market penetration can be varied by generating different distributions.

Mei/Rouphail ITRE Emulator

The Mei/Rouphail ITRE V2V communication module works as an add-in to the Aimsun simulation package. It simulates inter-vehicular communications with the same simulation step (between 0.1 and 1 second) as Aimsun simulates vehicle movements. The Aimsun simulation engine updates vehicle movements and computes everything once every simulation step. Inter-vehicle communications are therefore updated once every simulation step too, while in reality communications can happen at any time during this step time interval (say, 0.1 seconds).

It is assumed in the ITRE V2V module that any two v2v-equipped vehicles can communicate with each other as long as they are within a certain distance (say, 500 meters, computed based on the coordinates of the two vehicles) and data package transmittals between the two vehicles are always successful. The ITRE V2V module currently does not simulate any real communication protocols, such as Dedicated Short Range Communications (DSRC). To simulate those protocols, the simulation software has to be event-driven, which simulates each and every event involved in the communication protocols and can trace and analyze events at any time point. All the popular communication simulation packages that we are aware of are event-driven, such as NS2, NS3, and OMNet++. Simulation of communication channels, channel usage, and bandwidth are all available in these packages. One communication event using protocols like DSRC only take a few nanoseconds to complete. The 0.1-second simulation step of traffic simulation packages is therefore way too long to take channel usage and bandwidth into account with any realistic meaning.

There have been experiments and practices that marry time-driven traffic simulation packages with an event-driven communication simulation packages to make the v2v simulation more sophisticated and realistic. Some of those integrated packages are listed and briefly described in our proposal. For example, Jist/SWAN developed by Michael Zhang of the research team can simulate latency and interference and be used to develop/test communication protocols. VGSim uses DSRC / WAVE protocol.

Two response types were modeled, i.e., *Dynamic route diversion* (DRD) and *Variable speed limits* (VSL).

The VSL strategy is expected to minimize abrupt decelerations due to downstream roadway congestion. A connected vehicle with its path including the incident or bottleneck link is provided with distance-variant recommended speeds in the message. The recommended speed is for the vehicle to join the back of queue (or slow traffic) safely and smoothly. Specific implementation of VSL in this model includes the following steps:

- When the congestion information is confirmed based on the reliability index, the subject connected vehicle identifies the closest connected vehicle ahead traveling at atypical speeds.
- It then looks up a speed from the onboard VSL table based on the calculated distance to the vehicle ahead.
- It then applies the recommended speed limit. This recommended speed limit is the look-up speed plus the speed of the vehicle ahead and rounded to the nearest multiple of 5 mph.
- Transition from the current speed to the recommended speed follows the driver car following behavior rules embedded in Aimsun.

University of Arizona Emulator

The University of Arizona (UA) API is a “driver model” for the VISSIM model. Implemented equipped vehicles that broadcast Basic Safety Messages that contain GPS position data, speed, acceleration, status of braking system, etc. The external components can be a hardware of virtual OBE and a hardware of virtual RSE. OBE's can communication with each other or with the RSE. Vehicles can send other J2735 messages including Signal Request Message and can receive messages such as Signal Status Messages. Other messages are easy to add and the driver behavior can be modified to include change in speed, lane, etc. The market penetration can be varied by generating different distributions.

TCA Emulator

The Trajectory Conversion Algorithm (TCA) software, version 2.0 became available in January 2014. TCA is designed "to emulate the creation, capture and transmission of vehicle-based data under a range of configurable messaging strategies." [18] TCA is open source software written in Python and made available under the Apache 2.0 license.

TCA processes a vehicle trajectory file (produced either directly by the user or produced by Vissim or Paramics) and converts that information into the Basic Safety Messages (width and length of vehicle, latitude and longitude position, accuracy of position, speed, heading, steering wheel angle, acceleration in 4-dimensions, brake system status)[19] that the connected vehicles would produce. TCA then emulates the transmission of the BSM's each tenth of a second via DSRC, cellular-only, or via both modes simultaneously. If DSRC transmission is to be emulated, TCA requires a file identifying the coordinates of the RSE's with DSRC capabilities. A strategy file allows the analyst to define the criteria for determining the status of the vehicle (How long must it be stopped for it to be considered stopped; How fast it must go after a stop before a second stop can be counted; etc.) and the lag time (latency), loss percentage, and other factors affecting the successful transmission of the BSM by the vehicle.

Comparison of TCA Emulator to ITRE API

Error! Reference source not found. shows the flowchart of the *Trajectory Conversion Algorithm TCA)* Analytic Loop, in which TCA Software Version 2 (TCA-V or TCA-P 2.X) is a major component. As the TCA ConOps report indicates, "*the TCA Version 2 Software plays a role only in message emulation and does not address the complete analytical process*" and "*the objective of the TCA Version 2 software is to emulate the creation, capture and transmission of vehicle-based data under a range of configurable messaging strategies*".

Comparing the TCA Analytic Loop with Mei/Rouphail ITRE V2X simulation system, the components enclosed in the **red loop** all together do the complete work and function just like the ITRE V2X simulation system, as shown in Figure 2. The counterpart of "Traffic Simulation Software" in **Error! Reference source not found.** is "Aimsun Simulation Model" in Figure 2. The unctionality of the other four components in the red loop in **Error! Reference source not found.** is fully covered by the customized Python program in the ITRE simulation system. Specifically, these are the correspondences:

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[18] Taylor Deurbrouck, Jim Larkin, and Karl Wunderlich; Trajectory Conversion Algorithm (TCA) Software, Version 2: Concept of Operations; FHWA, Washington, DC, November 2013.

[19] RK Kamalanathsharma, Basic Safety Message Definitions, filebox.vt.edu/users/.../BSMVerbose.pdf, Virginia Polytechnic Institute, Accessed February 1, 2014.

Table 12: Comparison of TCA and ITRE V2V emulator functions.

TCA Analytic Loop	ITRE V2X (Mei/Rouphail) Simulation System
Draws vehicle trajectory data from VISSIM and Paramics (currently supported)	Draws vehicle trajectory data from Aimsun
TCA-V or TCA-P 2.X (i.e. TCA Version 2 software, primarily covered in the TCA ConOps report)	Traffic operation data retrieving from the Aimsun simulator and message triggering, forwarding, receiving, storing, and organizing
Simple Communication / Communication Analytics Module	Code for simulating inter-vehicular wireless communications (not a standalone module)
Measure Estimation Module	Code for assessing traffic conditions and deciding on control strategies (not a standalone module).
Connected Vehicle Application Emulation Software Module	Code to feed updated control parameters for equipped vehicles to the Aimsun simulator (not a standalone module).

According to the TCA ConOps report, TCA's Communication Analytics module implements dual wireless communication modes – DSRC and cellular. ITRE's communication module is similar to the Simple Communication module, which is a built-in module in TCA-V or TCA-P 2.X.

Both the TCA Version 2 Software and the ITRE V2V simulation system are written in Python, but integration of the two programs is not practical given the differing structures of the two programs. The TCA modules do not have exact equivalent modules in ITRE V2X.

As shown in the Source: Kittelson & Associates/USDOT

Figure 14, Aimsun offers an Application Programming Interface (API) for interfacing with external models or user-defined applications to allow them to interact with its internal micro-simulator. Python, a general computer programming language package, was employed for the development of a customized module to interface with Aimsun. The functionality of this module includes:

- interacting with Aimsun simulator through API to retrieve traffic operation data from the simulator as well as feed updated control parameters to the simulator;
- simulating inter-vehicular wireless communications such as message triggering, forwarding, receiving, storing, and organizing;
- assessing traffic conditions for message triggering or congestion information reliability evaluation; and
- based on the evaluation results and against some pre-defined criteria, deciding if any control strategies need to be deployed and, if so, feeding the required parameters to Aimsun simulator via the API.

Issues with Emulating the SPD-HARM/Q-WARN Prototype

While the Draft Report on Dynamic Speed Harmonization and Queue Warning Algorithm Design (Draft Design Document) has provided process flowcharts for the algorithms to be used in the test bed, it has to be noted that several algorithm implementation details are not covered in the Draft Design Document. Therefore inconsistencies may be unavoidable when they are implemented in a model using software.

First, the main purpose of models is always to try to mimic the real world. However, most of the time they cannot reflect the real world with a 100% accuracy, and assumptions about equipment operation and traveler behavior have to be made from time to time (these assumptions affect some of the user definable parameters used in the Prototype). The team will attempt to develop and calibrate the emulator model to match the PD Contractor algorithms as closely as possible. Secondly, differences in models, algorithms, and/or approaches employed between two simulation platforms may lead to inconsistencies where some traveler behavior can be modeled better on one platform than on the other. If the PD contractor has implemented and tested their algorithms on a simulation platform, then information on the exact model forms and the parameters used in the simulated prototype test (details of which are not provided in the current Draft Design Document), the IA team can adjust the parameters in our emulator to better match their simulated results.

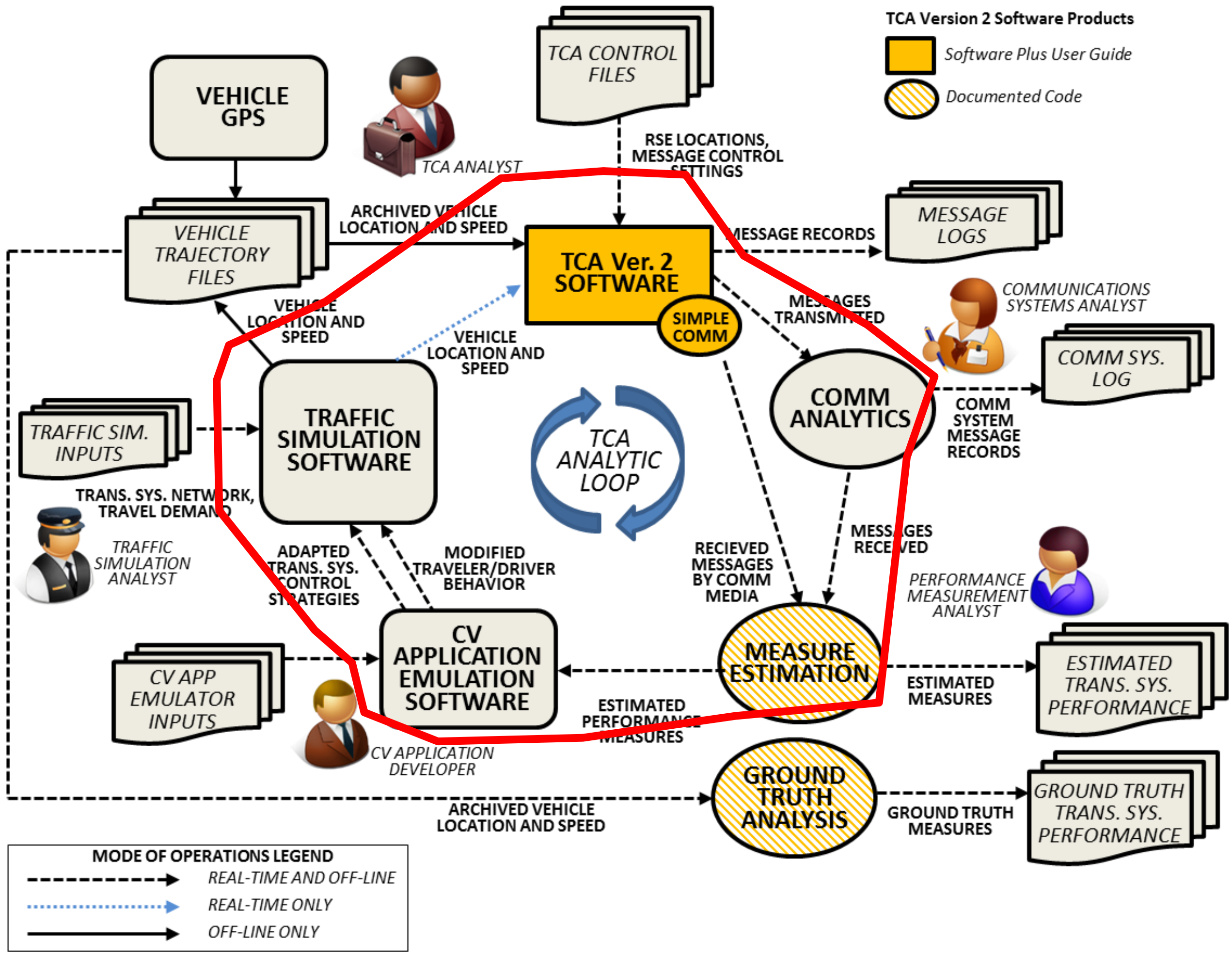
Recommended Emulation Approach to SPD-HARM/Q-WARN Prototype

Given the following:

- The selected test site is modeled in VISSIM.
- A VISSIM compatible SPD-HARM/Q-WARN Prototype emulator is required to conduct the Impact Assessment.
- The Mei/Rouphail ITRE V2X connected vehicle software is among the best documented and most recently developed software of this type with which the IA team is most familiar with.
- The different software structures do not facilitate direct incorporation of TCA into the ITRE V2X connected vehicle emulation software.
- It is feasible to emulate the communications modeling capabilities of TCA through sensitivity testing of different communication latencies and loss rates.

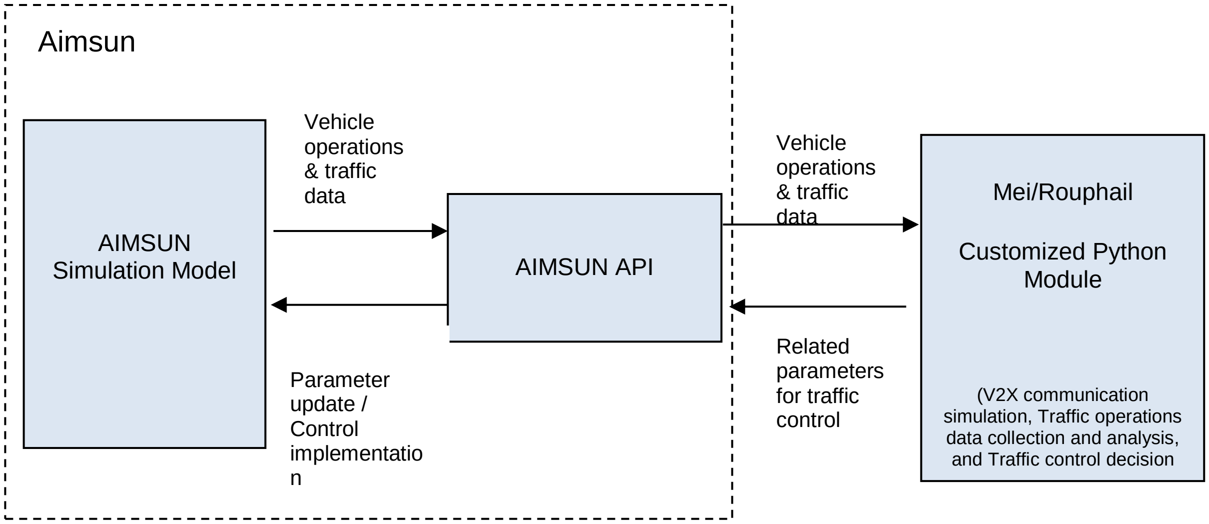
It is recommended that:

- The communications modeling capabilities of TCA be emulated in the VISSIM tests through a series of sensitivity tests related to communication latencies and losses.
- The ITRE V2X connected vehicle software be customized to emulate the SPD-HARM/Q-WARN Prototype, as described in Appendix B.
- The ITRE V2X connected vehicle emulator be written to work in VISSIM, borrowing TCA code if/and when it is cost-effective to do so.
- The functionality and general sensitivity of the customized ITRE connected vehicle emulator be compared to a standalone (black box) implementation of the SPD-HARM/Q-WARN prototype where the IA contractor can vary the inputs to observe their effect on the outputs (if such an implementation can be made available to the IA contactor by the PD contractor in the next 60 days).



Source: Kittelson & Associates/USDOT - Adapted from: Deurbrouck, Larkin, and Wunderlich, Trajectory Conversion Algorithm (TCA) Software, Version 2: Concept of Operations.

Figure 13. Illustration. TCA analytic loop real-time mode of operation.



Source: Kittelson & Associates/USDOT

Figure 14. Flow chart. ITRE V2X (Mei/Rouphail) software architecture.

APPENDIX B: EMULATOR OF SPD-HARM/QWARN PROTOTYPE

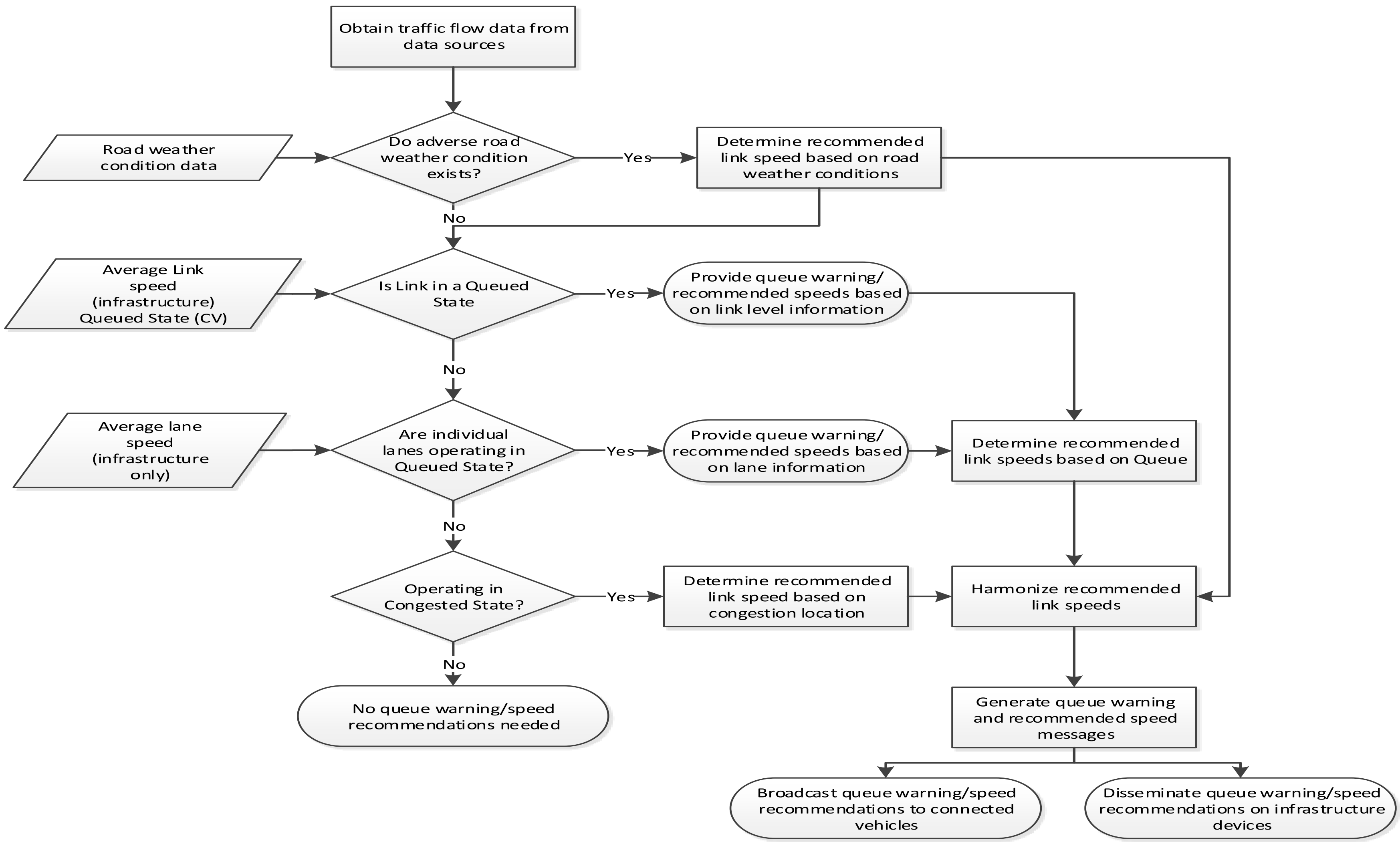
This appendix provides the specifications for the microsimulation model API emulator of the SPD-HARM/Q-WARN prototype algorithm. This description focuses on the parameters, variables, and user interface required to operate the algorithm in a microsimulation environment.

These specifications are for a microsimulation model emulation of the Battelle/TTI prototype Dynamic Speed Harmonization and Queue Warning Algorithm (the TTI Prototype), as documented in the January 15, 2014 draft Report on Dynamic Speed Harmonization and Queue Warning Algorithm Design, by Kevin Balke, Hassan Charara, Srinivasa Sunkari of the Texas A&M Transportation Institute (Balke Report).

OVERVIEW OF THE TTI PROTOTYPE

This overview of the TTI Prototype is taken from the Balke report.

"Data from multiple sensors will be used in the development of queue warning and speed recommendations. These data include both infrastructure-based and connected vehicle-based systems. After obtaining the data from the various sources, the data are processed and aggregated into a form that can be used by the various components of the algorithm. The prototype is envisioned to first check whether the roadway is operating in queued state (i.e., after breakdown where stop-and-go operations exist) or congested state (i.e., before breakdown has occurred but where speeds are below free-flow conditions). The analysis will first focus on looking across all lanes (i.e., the link level). If no queues or congestion are detected at the link level, then the analysis will look for queuing at the lane level. Recommended travel speeds will be developed for each situation. Using the results of the analysis, messages will be generated that provide both queue warning and recommended travel speeds to motorist driving through the section. The information will be disseminated to a vehicle using both connected vehicles as well as infrastructure devices."



Source: Balke, Charara, Sunkari

Figure 15. Flow chart. Overview of the TTI INFLO prototype.

MICROSIMULATION MODEL CODING REQUIREMENTS

Network Coding Requirements

The locations of in-road loop detectors (if any) must be specified in the microsimulation model.

The locations of changeable message signs (if any) and variable speed limit signs (if any) must be specified in the microsimulation model.

Vehicle SubTypes Required

The following five specialized vehicle sub-types will need to be coded in the microsimulation model for each major vehicle type (auto, bus, single unit truck, semi-trailer truck):

- Unconnected Vehicles
- Connected Vehicle1 (Not equipped with nomadic device or weather sensor)
- Connected Vehicle2 (equipped with weather sensor, but no nomadic device)
- Connected Vehicle3 (equipped with nomadic device, but no weather sensor)
- Connected Vehicle4 (equipped with nomadic device and weather sensor)

The proportions of each vehicle subtype within each major vehicle type are specified by the user.

LINK CORRESPONDENCE TABLE FOR EMULATOR

Directional DMA Links for the purposes of the emulator are defined as starting 25 feet (my guess) upstream of one detector and extending to 25 feet (my guess) upstream of the downstream detector (see page 18, Figure 3-1 of Balke report). (I think centering the link on each detector would be better).

Each directional DMA link in the network will be subdivided into sublinks of equal length of approximately, but no less than 1/10th of a mile long. For example, if the length of a DMA link (as defined by the distance between two adjacent infrastructure sensor stations) is 0.59 miles, then the link is divided into 5 sublinks, each with an approximate length of 0.12 mile. each.

- The emulator will need to either create a (or read a user provided) correspondence table between its internal DMA links and sublinks, the VISSIM detectors, and the VISSIM links.

SOURCES OF TRAFFIC VOLUME AND SPEED DATA FOR EMULATOR

The microsimulation model emulator of the TTI Prototype will need to draw traffic volume and vehicle state (speed, and queue status) data from in-road detectors and the connected vehicles in the microsimulation model.

Infrastructure Sources

The TTI Prototype is designed to work with "infrastructure-based roadway sensors utilizing *NTCIP 1209: Data Element Definitions for Transportation Sensor Systems*[20] "

Detectors collect data at the lane by lane level, which are aggregated to the station level (by averaging or summing across all lanes). The traffic status measured at the station is assumed to apply to the entire link.

Average station speeds and lane-by-lane speeds are compared to user-defined speed thresholds to determine if the speeds by link or by lane are operating in a "clear," "congested," or "queued" state. According to page 18 of Balke, "*For the prototype, initially only speed data will be used to determine operating states for the link and the lanes within the link*."

- The emulator will need to provide for user definable speed thresholds for "clear", "congested'" and queued detector station and lane status. The suggested defaults at this time are shown in **Error! Reference source not found.**.

Figure 16. Definition of traffic condition status (recommended defaults).

Congestion State	Average Road Detector Station Speed
Queued	<= 5 mph
Congested	> 5 mph and <=40 mph
Clear	> 40 mph

Data from the infrastructure sensors is collected every 20 seconds.

- The emulator will need to provide for random lane sensor and station sensor failure rates centered on values entered by the user. Failures consist of loss of data associated with that sensor for the duration.

The suggested default value for average percent failed sensors at any one time is 25%. Agencies with superior detector maintenance programs might select a lower value.

Vehicle Sources

Connected vehicles are assumed to broadcast data according to SAE J2735:2009 Basic Safety Message (BSM). Connected Vehicles will be polled by the emulator every 0.1 second (pg 20-21 Balke) for:

- Direction of travel,
- Latitude and Longitude,

[20] *National Transportation Communications for ITS Protocol – Data Element Definitions for Transportation Sensor Systems*. NTCIP 1209 v01.18 d. American Association of State Highway and Transportation Officials. April 2004.

- Speed (mph),
- brake status (on, off), and
- Length (feet)

In the TTI Prototype connected vehicles will be polled for visibility (miles) and pavement surface coefficient every 1.0 second (pg 21 Balke). However, since the prototype will also get weather data from stationary sources, this particular source does not need to be modeled in the emulator for microsimulation modeling purposes.

- The emulator will need to have a random factor centered on a user defined value to fuzzify[21] the Latitude and Longitude reported by the vehicle.

The suggested user range of error in GPS position (for a civilian unit) is 5 to 15 meters (15 feet to 50 feet). The lower values apply to optimal clear sky, dry conditions.[22] For the emulator a default value of 30 feet is suggested. The user should increase this value for facilities near tall buildings and mountains under humid conditions.

Thus the lane position of a connected vehicle cannot be known by the emulator.

The emulator will calculate the linear position of the vehicle within the link based on its fuzzified latitude and longitude.

The queued state of the connected vehicles will be determined based on the user set minimum threshold speed (pg 24 Balke). I suggest 5 mph as the default (pg 23 Balke). For the emulator we will assume that distance to adjacent downstream vehicle is not always available (because of unconnected vehicles in the stream), so speed will be the only indicator of queue state.

Figure 17. Definition of traffic condition status (recommended defaults).

Vehicle Queue State	Vehicle Speed
Queued	<= 5 mph
Not Queued	> 5 mph

ROAD WEATHER CONDITION DATA FOR EMULATOR

The TTI prototype will draw weather information from 4 sources: stationary sensor stations, mobile sensor stations, connected vehicles, and external weather providers (pg 29 Balke). Given the multiple sources, the emulator will not model each information source individually but will assume weather information is always available.

[21] Term coined by Karl Petty to indicate the intentional introduction of random error into an otherwise certainty.

[22] Wikipedia. (n.d.). *Error Analysis for the Global Positioning System*. Retrieved January 24, 2014, from Wikipedia: http://en.wikipedia.org/wiki/Error_analysis_for_the_Global_Positioning_System

- The user will provide the emulator with the weather data to be modeled, specifying the directional DMA links and 5 minute time periods to which each weather condition applies.

The weather data, which is sublink specific and updated every 5 minutes (pg 34 Balke), consists of:

- Pavement coefficient of friction factors (pg 30 Balke)
    - 0.80 for dry pavement (est.),
    - 0.60 for wet pavement, and
    - 0.25 for snow/ice on pavement.
- Visibility in miles.[23]
    - Good > 0.50 miles
    - Poor <=0.50 miles

For the weather speed recommendation emulator we will be using the look-up table approach described on page 45 of Balke. This provides for 3 pavement conditions (dry, wet, ice/snow) and 2 visibility conditions (good, poor).

The weather data is assumed to be applicable uniformly to the entire sublink across all lanes for the 5-minute period. It can vary between sublinks on the facility, but to simplify user input requirements, only link level weather will be input. Thus, weather will be uniform across all sublinks of the link, within the emulator.

QUEUE WARNING EMULATOR

The queue warning emulator has two functions:

- Detection of queues from road infrastructure and connected vehicles, and
- Delivery of queue warnings to connected vehicles and changeable message signs.

The TTI prototype will generate queue warning messages using three different algorithms operating in parallel: A TME (transportation management entity) Based Algorithm, a Cloud Based Algorithm, and a Vehicle Based Algorithm. Since for microsimulation modeling purposes the vehicle will be indifferent to the source of the queue warning, the emulator is designed to generate queue warning messages regardless of the source of information upon which they are based.

Every 1/10th of one second (page 42 Balke), at time “t”, the emulator checks the queue status of all sublinks. A sublink is defined by the emulator as “queued” if:

- There is a detector station located within the sublink AND a user specified minimum percentage of the lane detectors at the detector station are in “Queue” status.

[23] Values taken from Exhibit 10-15, 2010 Highway Capacity Manual

Inoperational lane detectors count against the percentage. See earlier description of how queue status is determined for detector stations; OR

- There are a user specified minimum number of connected vehicles located within the sublink at time "t" AND a user specified minimum percentage of those connected vehicles are in "Queued" status. Communication losses (temporarily disconnected connected vehicles) count against the minimum number and percentage of connected vehicles. See earlier description of how queue state is determined for connected vehicles; or

If a sublink is determined to be "queued", that status applies to all lanes within that sublink. In the case of detector stations that are determined to be "queued", that status applies to all sublinks for the link associated with that detector station.

- The emulator will have user selectable toggle switches to:
    - Turn on and off the ability to obtain queue status from all detector stations (so that an un-instrumented facility can be easily modeled), or to
    - Turn on and off the ability to obtain queue status from all connected vehicles (for modeling an instrumented facility without connected vehicles).
- The emulator will have user specifiable parameters for
    - Setting the minimum number of functional lane sensors in the sublink at time "t" for it to trigger "queued" status for the sublink;
    - Setting the minimum percent of lanes at a detector station that must be in "queue" to trigger a detector station "queue" status;
    - Setting the minimum number of connected vehicles that must be present in the sublink at time "t" for it to trigger "queued" status for the sublink;
    - Setting the minimum percent of connected vehicles that must be in "queued" status to trigger "queued" status for the sublink.

The back of queue is the farthest upstream sublink of a continuous set of sublinks in "queued" status regardless of whether the status was determined via detectors or connected vehicles. There can be several back-of-queues sublinks on a facility or a link.

Queue warning messages are delivered to all connected vehicles and changeable message signs located within a user specified distance upstream of the back of queue at time "t". Page 40 of Balke suggests the distance be 10 miles.

How the driver should respond to them is not currently specified for the TTI Prototype. I would suggest for the purpose of simulating the effects of the TTI prototype that the message (which includes the number of miles to the back of queue) is repeated each mile (with no change in driver behavior) until the vehicle is within one mile of the back of queue at which point:

- The driver's target car-following headways for all speeds are increased in the microsimulation model by a user defined percentage (say 10% for starters).
- The driver's desired travel speed is reduced in the microsimulation model by a user defined percentage (say 10% for starters).

- The emulator will need to provide for user specified percentage increases in car following headways and decreases in desired speed. I would suggest 10% default values for now.

WEATHER SPEED RECOMMENDATIONS EMULATOR

The TTI Prototype provides for generating weather recommended speeds for two levels of visibility (good and poor) and three levels of pavement condition (dry, wet, icy/snow) (page 45 Balke) using a table of values input by the user. The emulator will do the same.

- The emulator will provide for a user definable 2x3 look-up table of speed recommendations by pavement condition and visibility.
- shows table with initial recommended default values for consideration.

Figure 18. Weather speed recommendations look-up table (recommended defaults shown).

	PAVEMENT CONDITION		
Visibility	**Dry**	**Wet**	**Ice/Snow**
Good (>0.50 miles)	Driver's Desired Speed for link under ideal conditions	Minimum of 55 mph or 90% of ideal	Minimum of 45 mph or 70% of ideal*
Poor (<=0.50 miles)	Minimum of 45 mph or 75% of ideal	Minimum of 35 mph or 60% of ideal	Minimum of 25 mph or 55% of ideal*

*Assumes plowed road.

SPEED HARMONIZATION RECOMMENDATIONS EMULATOR

The TTI Prototype will update speed harmonization recommendations once every 5 seconds. The recommended speeds may change no more than 5 mph every 15 seconds (page 49 Balke). Since the recommended speeds cannot be changed more frequently than once every 15 seconds, the emulator will compute speed harmonization recommendations only once every 15 seconds and round the recommendations down to the nearest 5 mph divisible value.

Note that the infrastructure detector speeds are updated every 20 seconds.

The TTI Prototype makes use of historic speeds to fill in missing data. The simulation emulator will NOT make use of historic data because the quality of such data is site and situation specific, and would cloud the comparison results.

Determination of Existing Sublink Speed

The determination of existing sublink speeds will follow the algorithm:

- For each link with a user defined minimum number and minimum percentage of lane detectors in operation, the emulator will compute the simple average speed across lanes. This same observed average speed is assigned to all sublinks within the link.
- For each sublink with a user defined minimum number of connected vehicles the emulator should compute the simple average speed across all connected vehicles in the sublink over the 15 second time period.
- The connected vehicle speeds will override the detector speeds for all sublinks where a detector is NOT present.
- For sublinks where a detector is present AND both connected vehicle speeds and detector speeds are available, the lower of the two speeds is the selected speed. (Figure 6-1, page 50 of Balke).
- Sublinks without observed speeds from the prior 4 steps are assigned a “No Data” status for speed.

The prototype provides for smoothing of the connected vehicle speeds over a user specified “N” 5-second periods. The emulator will automatically address this by computing average 15 second speeds (where N = 3) for connected vehicles. The number of periods for smoothing will not be user adjustable.

Calculation of Recommended Sublink Speeds for Speed Harmonization

Following the general approach described on pages 48-57 of Balke for the speed harmonization prototype, the emulator will use the following algorithm to determine the recommended speeds for the connected vehicles and the gantry signs.

For each 15 second period, the emulator will identify adjacent sublinks with similar enough observed speeds that should be grouped together for speed harmonization purposes.

- Start with first upstream sublink.
    - Set maximum and minimum speed thresholds for the first group of sublinks based on this first sublink.
    - Add and subtract ½ of user specified acceptable range of speeds to the observed mean speed for grouping sublinks together. Use Seattle range of 12 mph as default. Thus, if mean observed speed is 57 mph, the acceptable range for adding downstream sublinks to this group for speed harmonization purposes is 51 mph to 63 mph.
- Continue to downstream sublink
    - If candidate downstream sublink has “no data”, add it to the speed harmonization group, go to next sublink downstream
    - If observed mean speed of downstream sublink falls within acceptable range, add it to the speed harmonization group.
        - Recompute means speed and max/minimum range for augmented group of sublinks.

  - If candidate downstream sublink's observed mean speed falls outside the speed range for the group then:
    - check to see that group of sublinks can be traversed at the mean speed for the group in less than 15 seconds.
      - If less than 15 seconds, add next downstream sublink (regardless of its mean speed), recompute average and range and continue on.
      - If greater than or equal to 15 seconds,
        - stop adding sublinks to this group.
        - Start new group (go back to step 1)
- Repeat steps 1 and 2 until all sublinks in analysis direction have been grouped.
  - If last group is less than 15 seconds to traverse, add last group to second to last group.
- Set recommended speeds for connected vehicles within each sublink group
  - Round mean speed of group up to nearest 5 mph, subject to not exceeding the user specified posted speed limit or falling below the user specified minimum speed for the facility.
    - This is the initial recommended speed for all connected vehicles within the group of sublinks.
  - Check initial recommended speeds for transitions between adjacent groups of sublinks.
    - If the upstream speed is more than 5 mph greater than the downstream speed, transition in 5 mph increments for upstream sublinks within the upstream group.
- Set recommended speeds for gantries located within each sublink group
  - The gantry speed in the sublink in which the gantry is located should match the recommended connected vehicle speed for the same sublink.

Note that this logic allows the recommended speeds between gantries to differ by more than 5 mph if they are more than ½ mile apart. This provides flexibility to accommodate more widely spaced gantries. Regardless, the logic does not allow speed changes of greater than 5 mph for every ½ mile of facility.

USER DEFINABLE PARAMETERS FOR EMULATOR

Error! Reference source not found. provides a list of the user definable parameters that need o be provided in the emulator.

identifies the microsimulation model parameters required to test the prototype under varying conditions.

Figure 19. User definable parameters for TTI prototype emulator.

User Definable Q-WARN Parameter	Comment
1. Average Speed Threshold for Queued State	Set at 5 mph for all tests
2. Min. Seconds below speed threshold before Lane detector is considered to be in "Queue"	Perform side tests to find best values under varying equipment error rates.
3. Criteria for Link in "Queue" state a. Number Lane Detectors in "Queue". b. Percent Lane Detectors in "Queue".	Perform side tests to find best values under varying equipment error rates.
4. Min. Seconds below speed threshold before connected vehicle is considered to be in "Queue"	Perform side tests to find best values under varying equipment error rates.
5. Criteria for SubLink in "Queue" state a. Number connected vehicles in "Queue". b. Percent connected vehicles in "Queue".	Perform side tests to find best values under varying equipment error rates.
6. Upstream broadcast range for queue warning	Set at 1 mile for all tests
User Definable SPD-HARM Parameters	**Comment**
7. Recommended speeds by visibility and pavement condition type	Set at values shown in of Appendix B
8. Criteria for Valid Link Speed determination: a. Number Lane Detectors in operation b. Percent Lane Detectors in operation.	Perform side tests to find best values under varying equipment error rates.
9. Criteria for Valid SubLink Speed determination: a. Number connected vehicles present with comm. b. Percent connected vehicles present with comm. c. Smoothing period (min.secs) for spd estimates.	Perform side tests to find best values under varying equipment error rates.
10. Speed range for determining troupes for SPD-HARM	Perform side tests to find best values under varying equipment error rates.
11. Maximum and Minimum speeds for SPD-HARM	Set at 70 mph and 25 mph for

Figure 20. Parameters for testing of TTI prototype in microsimulation model.

USER DEFINABLE MICROSIM PARAMETER	COMMENT
1. Percent Connected Vehicles	Net percent connected vehicles that receive the SPD-HARM message and comply with it.
2. Road detector spacing	Average miles between traffic state detection (volume and average speed by lane)
3. Changeable or dynamic message sign spacing	Average miles between dynamic or changeable message signs capable of displaying recommended speed.

EXAMPLE APPLICATION OF SPD-HARM PROTOTYPE

The text and figures below describe how the SPD-HARM prototype would function on a recurring bottleneck.

- The SPD-HARM prototype will smooth out deceleration (by spreading it out over a greater distance upstream), but will not apply to acceleration. People leaving a queue will accelerate as they do now.
- While the SPD-HARM concept includes prediction of recurring congestion, the prototype does not yet have that feature.
    - Thus recurring queues due to bottlenecks will continue to form under the prototype.
        - The starting time of the queue may be delayed a few seconds because SPD-HARM will slow down the arrival of demand at the bottleneck by at most a few seconds as bottleneck speeds gradually drop to speeds typical of bottleneck capacity (35-40 mph).
- The speed and capacity of the bottleneck itself will not be affected by the prototype.
    - The queueing would therefore persist for about the same amount of time under the SPD-HARM prototype, because the capacity and speed of the bottleneck would be essentially unchanged under the prototype.
- The recommended speeds produced by the prototype for individual troupes of sublinks may drop or increase abruptly (for that specific troupe) at the beginning and end of queue formation. (see cell [16:30, 3.30] in **Error! Reference source not found.**, for xample. The speed drops from 60 to 30 in a 15 minute period)
- **Error! Reference source not found.** shows how the SPD-HARM prototype would ork for the hypothetical recurring bottleneck shown in **Error! Reference source not found.**. The roughly "flashlight" shaped box in **Error! Reference source not found.** shows where SPD-HARM would lower the speeds as compared to **Error! Reference ource not found.**.
- <u>At a big picture level</u>, the prototype will generally lower the average speed on the facility, increase the variance of speeds on the facility (by increasing the number of cells with speeds significantly less than the average), and decrease the maximum cell-to-cell variation in speeds over distance on the facility.
    - Microscopic simulation and the small scale demonstration will no doubt reveal some subtleties in this big picture.

Figure 21 is a hypothetical recurring bottleneck before SPD-HARM. Each cell shows the average speed of traffic within that 15 minute by 0.3 mile long cell. A queue starts to form at 16:45 and persists for one hour.

Without SPD-HARM — Mean= 66.50 mph StDev= 11.14 mph CofV= 16.8% MaxD= 20 mph

Time	0.30	0.60	0.90	1.20	1.50	1.80	2.10	2.40	2.70	3.00	3.30	3.60	3.90	4.20	4.50	4.80	5.10	5.40	5.70	6.00	6.30	6.60 miles
19:30	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
19:15	70	70	70	70	70	70	70	70	70	70	70	70	70	70	65	70	70	70	70	70	70	70
19:00	70	70	70	70	70	70	70	70	70	70	70	70	70	70	60	70	70	70	70	70	70	70
18:45	70	70	70	70	70	70	70	70	70	70	70	70	70	70	55	70	70	70	70	70	70	70
18:30	70	70	70	70	70	70	70	70	70	70	70	70	70	70	50	70	70	70	70	70	70	70
18:15	70	70	70	70	70	70	70	70	70	70	70	70	70	65	45	65	70	70	70	70	70	70
18:00	70	70	70	70	70	70	70	70	70	70	70	70	70	60	40	60	70	70	70	70	70	70
17:45	70	70	70	70	70	70	70	70	70	70	60	40	20	15	35	55	70	70	70	70	70	70
17:30	70	70	70	70	70	70	70	70	70	60	40	20	15	15	35	55	70	70	70	70	70	70
17:15	70	70	70	70	70	70	70	70	60	40	20	15	15	15	35	55	70	70	70	70	70	70
17:00	70	70	70	70	70	70	70	70	70	60	40	20	15	15	35	55	70	70	70	70	70	70
16:45	70	70	70	70	70	70	70	70	70	70	60	40	20	15	35	55	70	70	70	70	70	70
16:30	70	70	70	70	70	70	70	70	70	70	70	70	70	60	40	60	70	70	70	70	70	70
16:15	70	70	70	70	70	70	70	70	70	70	70	70	70	65	45	65	70	70	70	70	70	70
16:00	70	70	70	70	70	70	70	70	70	70	70	70	70	70	50	70	70	70	70	70	70	70
15:45	70	70	70	70	70	70	70	70	70	70	70	70	70	70	55	70	70	70	70	70	70	70
15:30	70	70	70	70	70	70	70	70	70	70	70	70	70	70	60	70	70	70	70	70	70	70
15:15	70	70	70	70	70	70	70	70	70	70	70	70	70	70	65	70	70	70	70	70	70	70
15:00	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
	Distance Downstream					Direction of Flow -->									Bottleneck							

Figure 21. Recurring bottleneck without SPD-HARM.

The diagram below shows how the anticipated speed of traffic in each cell, assuming compliance with the SPD-HARM prototype recommended speeds. Note that there are some cells (those with average speeds below 30 mph), where SPD-HARM would show no recommended speed (or might show 30 mph), but traffic is assumed to slow down because it can see the back of queue up ahead.

With SPD-HARM1 — Mean= 63.5 mph StDev= 13.4 mph CofV= 21.1% MaxD= 5 mph

Time	0.30	0.60	0.90	1.20	1.50	1.80	2.10	2.40	2.70	3.00	3.30	3.60	3.90	4.20	4.50	4.80	5.10	5.40	5.70	6.00	6.30	6.60 miles
19:30	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
19:15	70	70	70	70	70	70	70	70	70	70	70	70	70	70	65	70	70	70	70	70	70	70
19:00	70	70	70	70	70	70	70	70	70	70	70	70	70	65	60	70	70	70	70	70	70	70
18:45	70	70	70	70	70	70	70	70	70	70	70	70	65	60	55	70	70	70	70	70	70	70
18:30	70	70	70	70	70	70	70	70	70	70	70	65	60	55	50	70	70	70	70	70	70	70
18:15	70	70	70	70	70	70	70	70	70	70	65	60	55	50	45	65	70	70	70	70	70	70
18:00	70	70	70	70	70	70	70	70	70	65	60	55	50	45	40	60	70	70	70	70	70	70
17:45	70	70	70	65	60	55	50	45	40	35	30	25	20	15	35	55	70	70	70	70	70	70
17:30	70	70	65	60	55	50	45	40	35	30	25	20	15	15	35	55	70	70	70	70	70	70
17:15	70	65	60	55	50	45	40	35	30	25	20	15	15	15	35	55	70	70	70	70	70	70
17:00	70	70	65	60	55	50	45	40	35	30	25	20	15	15	35	55	70	70	70	70	70	70
16:45	70	70	70	65	60	55	50	45	40	35	30	25	20	15	35	55	70	70	70	70	70	70
16:30	70	70	70	70	70	70	70	70	70	65	60	55	50	45	40	60	70	70	70	70	70	70
16:15	70	70	70	70	70	70	70	70	70	70	65	60	55	50	45	65	70	70	70	70	70	70
16:00	70	70	70	70	70	70	70	70	70	70	70	65	60	55	50	70	70	70	70	70	70	70
15:45	70	70	70	70	70	70	70	70	70	70	70	70	65	60	55	70	70	70	70	70	70	70
15:30	70	70	70	70	70	70	70	70	70	70	70	70	70	65	60	70	70	70	70	70	70	70
15:15	70	70	70	70	70	70	70	70	70	70	70	70	70	70	65	70	70	70	70	70	70	70
15:00	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
	Distance Downstream					Direction of Flow -->									Bottleneck							

Figure 22. Recurring bottleneck with SPD-HARM prototype.

The mean speed, standard deviation (StDev), coefficient of variation (CofV) and maximum speed deceleration in mph are shown along the top of each figure.

APPENDIX C: RESPONSE TO FHWA COMMENTS VERSION 3.0

Deliverable Title: Task 2 INFLO Impact Assess Plan - Draft Final Version 3.0 (dated January 2014)

Deliverable Date: February 2, 2014

Comments Date: February 14, 2014

GENERAL COMMENTS

1. I reviewed this plan and it looks pretty good. I have one comment with stakeholder comment number 95, it's worth exploring the modifications or changes that would be needed to offer the INFLO PD app as “factory installed” option using the OEM based telematics and Infotainment systems. (*Mohammed Yousuf, USDOT*)

   Response: The exploration of this OEM implementation option is a good suggestion, but will have to be undertaken by others. It is outside the scope of our current task order.

2. I have a few general comments on the report (very hard reading for me and a long report) (*Dr. Osman Altan, USDOT*):
   a. Many places in the report V2X is mentioned, but if I remember correctly the prototype will primarily work via V2I and I2V, am I wrong there. V2X comprehends V2V also, and this is going to be extremely important in the future based on the recent NHTSA announcement, however, this should be clarified.
   b. Throughout the report they talk about how weather information will impact the performance of the system. Also, at one place they talk about road geometry being one of the parameters. If those are considered as factors, then some others might be considered, like; temporary lane/road closures, detours, reduction/increase in the number of lanes, merging of highways, demerging, highway entrances/exits, etc.

   Response: Point is well taken. The prototype is more precisely and accurately described in the PD contractor documents. For the purposes of the impact assessment, we will be testing different latencies and communication loss rates, but we will not be predicting what those rates would be for different communication methods and technologies. For our purposes, therefore the precise method by which a vehicle receives or transmits its information (whether from road infrastructure or from another vehicle) will not impact the impact assessment tests. We believe the impact assessment results can be applied to an assessment of V2V as well as V2I by looking up the test results for the appropriate ranges of latencies and error rates.

   Regarding the second point related to the many factors that can impact performance, they are all valid suggestions. We will not be able to test the infinite number of possible *combinations of these factors and subfactors within the finite constraints of this task order, but our experimental plan is designed to cover a representative range of possible combinations so that the reader can do their own extrapolations to other combinations of factors not specifically tested by us.*

3. The revised plan is very thorough. The authors have done an excellent job of addressing comments from stakeholders and other reviewers. I do have a couple of comments related to measures that will be calculated and these are documented in the Detailed Comments section. Also, please incorporate suggestions made by Joe Bared (FHWA) on safety measures and Karl Wunderlich (Noblis) on determining probabilities for weather and incident scenarios at the meeting on 5 February. (*Meenakshy Vasudevan, Noblis*)

   Response: Comment appreciated. Joe Bared's and Karl Wundelrich's comments are repeated below:

   - *For performance measures consider:*
     - *Latent delay (delay accumulated by vehicles unable to enter facility during simulation period)*
     - *Number of stops*
     - *For safety proxies, consider:*
       - *frequencies of near conflicts, with near conflicts defined as "time to collision" of 1.5 to 1.0 seconds.*
       - *Number of lane changes*
   - *When developing probabilities of weather and incidents for computation of average annual performance consider sensitivity testing of results using weather and incident types appropriate to other parts of the country. Talk to Booz Allen (the DMA evaluator) about how the sensitivity tests might help them extend results to national conclusions.*

   Our responses are as follows:

   - *Yes, we will tally and report latent delay*
   - *Yes, we will report number of stops*
   - *We will look into reporting the frequencies of near conflicts. We are a bit pessimistic about our ability to gather this information and whether we can get meaningful conclusions from it. In a simulation environment the car following rules in the simulation model generally prohibit "near conflicts", so we are not sure that this will be a valuable microsimulation model output. As for the small scale demonstration, we do not think the level of detection will be sufficiently precise and pervasive to allow meaningful measurement of near conflicts in the field.*
   - *We will look into reporting number of lane changes from the microsimulation model runs– it is not a standard microsimulation output. As for the small scale demonstration, we will report it if it can be gathered with the infrastructure in place, but we suspect the detection may not be sufficiently precise or pervasive to capture lane changes by non-connected vehicles.*
   - *Yes, we will conduct sensitivity tests of different weather and incident probabilities, and talk to the DMA evaluator about how this can help them in their work.*

4. I have a general concern about reliability, environmental and safety performance measures in general since they look too simplistic, at least the way they are presented in this report. Is this because they are deemed to be less important than the others as far as these applications are concerned? If so, some kind of importance ranking might help. (*Kaan Ozbay, NYU*)

   Response: Our impact assessment will produce the numerical results from which readers and evaluators can extrapolate their conclusions applying the relative weights that they deem appropriate for their particular deliberations.

DETAILED COMMENTS

ID	Page	Section	Comment	Reviewer	Response from Contractor	Response Verification
1	10	Executive Summary	In the bulleted list, there is a talk about PII, but nothing about security, is this ignored at this time. Security is important mainly from two aspects; unauthorized access to PII and broadcasting unauthorized messages that could compromise the system. I did not see any mention of security anywhere else in the report also.	Altan	A very legitimate question. We have no plans to quantitatively address comm. security issues. That is outside our scope.	
2	11	Executive Summary	Table 1. In the table, ‘user acceptance’, ‘market penetration’, etc. is used as performance metrics. On the other hand there are factors that will impact the market penetration, mainly, the cost of the system, periodic charges to the user, etc. Also, is this service going to be offered by public or private sector. If private sector, then who will provide, automakers, suppliers, etc., their willingness, business models, etc. These are secondary factors but will impact the market penetration, and as I see market penetration is very important factor in the rest of the report.	Altan	All, excellent points and good questions. We will be focusing our tests on sensitivity testing of how changes in the net effects of these factors will affect the success of SPD-HARM and Q-WARN. A few of these factors we will investigate in a bit more detail. But most of the additional factors listed, will be dealt with in qualitative discussion.	
3	16	Figure 1	Typo – Vecicle should be Vehicle	Ozbay	Thanks. fixed.	

ID	Page	Section	Comment	Reviewer	Response from Contractor	Response Verification
4	18	1.5	I am not sure if this was raised before but I would like to pose the following question. Based on the Q-Warn connected vehicles will be recommended a lower speed. Can this create problems for unconnected vehicles that do not expect such a change in speed, especially for low penetration levels of CVs?	Ozbay	Good question. The Q-Warn prototype message will not include a speed. We will not be addressing this particular unconnected vehicles issue quantitatively in the IA tests.	
5	20	2.1	I am not very clear that the existing micro-simulation software programs are appropriate to measure safety related performance measures shown in Table 3.	Ozbay	A legitimate concern which we (and other microsimulation modelers in the past) had hoped to deal with through proxies. However, as pointed out in Comments # 10, and #17, the proxies are not recommended.	

ID	Page	Section	Comment	Reviewer	Response from Contractor	Response Verification
6	21, 97	2.2	VHQ: While visual inspection is fine, my suggestion is to please also report out the queue length (number of vehicles in queue or distance over which queue extends) and VHQ by facility and time. Comment #9: Q-WARN, as you rightly noted in your response, will cause diversions. So drivers that re-route or change lanes will not contribute to the queue. That means we should see a reduction in queue length and duration. My recommendation is to keep queue length and duration.	Vasudevan	Queue length and duration per link is a standard microsimulation output easy to report. We are concerned however that it will not give a clear result. We will report it and see what happens. Neither the small scale demonstration nor the microsimulation will predict diversion effects of advance queue warning. We will be able to discuss it speculatively (in other words, if demand dropped 10%, the effect on predicted performance would be Y%).	

ID	Page	Section	Comment	Reviewer	Response from Contractor	Response Verification
7	22, 97	2.4	"Initial hypothetical tests of the SPD-HARM prototype suggest that the computed variance for the facility will increase with SPD-HARM, rather than decrease. So speed variance may not be a desirable performance measure for the prototype." This is contradictory to what is expected of SPD-HARM. As far as I know, SPD-HARM should be able to reduce the variance of speeds across lanes within a link, and variance of speeds between adjacent links – not necessarily over the entire roadway. How was the variance calculated in the example? Maximum speed difference is a fine performance measure to examine; however, I think variance should also be examined. From response to comment #8 on page 97 it appears that the speed variance will be measured in lieu of shockwave duration, number or speed. Please clarify.	Vasudevan	Agreed, if by "variance between links" the reviewer means "the maximum speed difference between links." The classically computed variance of sublink mean speeds by 15 minute time period, computed over the entire facility and peak period however will go up as illustrated in the example given at the end of Appendix B. Response to comment #8 reflected our thinking before we performed the excel spreadsheet tests of the prototype.	
8	24	2.6	Does the travel time mean link, trip or network travel time? For this application, I assume link travel time might make more sense.	Ozbay	It will be the mean trip travel time (Total VHT/Total Vehicle-Trips).	
9	24	2.7	Environmental effects: Is it safe to assume that there will be a linkage to MOVES or MOVES based rates for emissions?	Ozbay	We will use EPA recommended national average rates they derived employing MOVES.	

ID	Page	Section	Comment	Reviewer	Response from Contractor	Response Verification
10	26	2.9	I am not sure why more realistic surrogate safety measures cannot be used. The amount of work is marginal to calculate these given the fact that vehicle based speed and location information will be extracted from the simulation no matter what.	Ozbay	See comment #17 about difficulty finding correlations. Also see stakeholder comment (Schladover #14) about unreliability of safety proxies.	
11	29, 98		Per comment #18 on page 98, 511.org is specific to the SF Bay area. Please drop the ".org" from Figure 4 and text that follows.	Vasudevan	Done.	
12	29	Chapter 3	Figure 4 (cosmetic change). Very hard to read the text, should be full page in landscape format. It is a very important figure.	Altan	Good suggestion. Done.	
13	30	Section 3.3	Mentions that 'DSRC range is 300m but can be greater under favorable conditions'. If this is one of the variables in IA, then they should consider the fact that 'DSRC range can be shorter under unfavorable conditions'.	Altan	True, range could be worse. The specific range of DSRC will not be a factor in our impact assessment. We will be looking at % communications lost, regardless of cause.	

ID	Page	Section	Comment	Reviewer	Response from Contractor	Response Verification
14	31	3.3	“We propose to employ the following definitions regarding the time frame: “near term” implies deployment before 2020, “mid-term” is 2020 to 2030, and “long term” is post 2030” Please cite the work done under the Foundational phase here as I believe these time frames came from the earlier work.	Vasudevan	It is an extrapolation to specific calendar years of the general time periods cited in Chapter 6, Concept Development and Needs Identification for Intelligent Network Flow Optimization (INFLO) Concept of Operations, June 2014.	
15	34	Section 3.5	Figure 7. Important figure, how did they obtain the family of curves, is there a formula or is it empirical based on some kind of simulation. They should mention that.	Altan	The figure is intended to be illustrative of the underlying approach we will use. We intend to assume the factors are independent. Therefore we can simply multiply the probabilities of the individual factors to obtain the combined probability for all.	
16	36	Section 3.6	Figure 8. Important figure, how did they obtain the family of curves, is there a formula or is it empirical based on some kind of simulation. They should mention that.	Altan	Same response as for Figure 7.	

ID	Page	Section	Comment	Reviewer	Response from Contractor	Response Verification
17	42	4.2.3	I am not clear how "prediction of changes in incident frequencies" will be made given the recognition of the current simulation tools inability of simulating incidents. Is it from the surrogate measures? But correlating surrogate safety measures with incidents is not trivial. This needs some clarification.	Ozbay	Our stakeholders also commented on the difficulty of extrapolating surrogates to safety. Our plan therefore is to draw on European and Seattle/Minneapolis accident reduction experience to estimate the likely change in frequencies.	
18	42	4.2.3	Excluding weekend / holidays and off-peak periods can be problematic because some of the major safety and reliability benefits can be observed when traffic is not very congested but disrupted for some reason like weather, slow moving vehicle or an incident (especially secondary incidents can be more likely to happen under less congested high speed traffic conditions). Incidents occurring during these excluded time periods are also in general high severity incidents that can cause longer and more severe delays. Also, weekends or holidays, have their own traffic characteristics, at least from some urban locations.	Ozbay	Good point. We will provide advice on how readers can extrapolate our results to weekends, holidays, and off-peak periods.	
19	60	Appendix	Editorial. Numbering of the Comparison section is incorrect. Should A.3.4.	Vasudevan	Thanks. fixed.	
20	61	Table 12	I don't understand the highlighted row. What is being compared there?	Vasudevan	The row is intended to show what parts of the analytic loop are covered by the specific TCA software version.	

ID	Page	Section	Comment	Reviewer	Response from Contractor	Response Verification
21	61		"According to the TCA ConOps report, TCA's Communication Analytics module will be more sophisticated than ITRE's communication module." I don't believe that claim was made. The TCA 2.1 version implements a simple communications model. TCA 2.2 will implement a more sophisticated communications model.	Vasudevan	Correction accepted.	
22	73	Appendix B	"The TTI Prototype will update speed harmonization recommendations once every 5 seconds. The recommended speeds may change no more than 5 mph every 15 seconds (page 49 Balke). Since the recommended speeds cannot be changed more frequently than once every 15 seconds, the emulator will compute speed harmonization recommendations only once every 15 seconds and round the recommendations down to the nearest 5 mph divisible value." With some simulation tools this can be a problem if the speed information will be given the built-in VMS functionality because once a vehicle enters a link, it is assumed to see the VMS and for long links this speed will remain the same for that vehicle until it leaves the link. This might not allow the change of the speed limit once they enter a link. This might create a redundancy in terms of updating the speed recommendations every 5 seconds.	Ozbay	Excellent point. We will discuss with the VISSIM developers how this might affect the simulation of speed harmonization and what options might be available for overcoming this modeling issue.	

APPENDIX D: RESPONSE TO FHWA COMMENTS VERSION 2.0

Deliverable Title: Impacts Assessment Plan for Dynamic Speed Harmonization with Queue Warning (V2.0)

Deliverable Date: October 31, 2013

Comments Date: November 18, 2013

Response Date: January 26, 2014

RESPONSES TO GENERAL COMMENTS

1. This version (Version 2) of the impact assessment plan is substantially better than Version 1. The current version of the plan reflects a more thoughtful approach to the overall assessment goals and specific methods to achieve these goals. (*Bruce Hellinga*)

R1. We thank the reviewer for his remarks.

2. The document reads well and they have done a good job of putting everything together. *(Mohammed Yousuf*)

R2. We thank the reviewer for his remarks.

3. The report is very thorough. (*Joe Bared*)

R3. We thank the reviewer for his remarks.

4. Significant thought has gone in to the development of this version of the plan. The approach of reducing the scenarios by defining composite factors was very interesting and insightful. However, my main concern with this approach is that it may not help address some of the questions. Is it more complicated to deduce results/impacts from these condensed scenarios than to run the model several times using automated techniques and processing tools? For example, how would you address the question as to what market penetration is required for speed-harmonization to become effective? Or what are the impacts if there is 50% compliance in the mid term? That is embedded within response level. (*Meenakshy Vasudevan*)

R4. We appreciate the reviewer's comment.
We do believe that given the time and budget constraints of the study and also given that at this point we do not know the details of the prototype algorithm and the effort required for implementation into simulation, the proposed approach will address most of the questions.
We believe that time spent on deduction will be more valuable to the project results than more automated model runs. For example, compliance is a function of communication failure, market penetration, and other factors. The effect of market penetration alone can be completely washed out by communication failures or if the user ignores the displayed message. However; traffic simulation models are not currently designed to predict compliance based on these other factors, so compliance must be assumed. Multiple model

runs of different levels of compliance will be valuable. But multiple runs of different combinations of market penetration and communication failure are not as valuable, because our knowledge of compliance is so rudimentary. We can apply simple probability theory to identify which combinations of market penetration and other factors result in similar compliance results. Microsimulation of those combinations would not be informative.

RESPONSES TO DETAILED COMMENTS

ID	Page	Section	Comment	Reviewer	Response from Contractor	Response Verification
1	8	ES	Development of the Experimental Plan Add - Can nomadic devices be integrated with in-vehicle infotainment (This is from the PD TOPR, but it is unlikely we will know the outcome from PD effort.)	Yousuf	We can add this question as an extra question not included in the IA TOPR. However, this would seem to be logically a question that the PD contractor, who developed the algorithm, could test and answer. We can report their conclusions in the IA results, if desired. But we will be unable to independently confirm this.	
2	10	Table 1	Test 1: Typo. SPD-HARM and Q-WARN are “applications” in the INFLO “bundle.”	Vasudevan	Corrected	
3	10	Table 1	Test 3: I don’t think the PD Contractors is going to compare effectiveness DSRC vs. cellular. Their prototype will include both communication types – some components will use DSRC while others will use cellular. Please confirm this with the PD Contractor.	Vasudevan	We also believe that this is the case. It will be confirmed when details about the prototype are available. If the PD Contractor will not examine the implications of communications hardware choices, we will not be able to do so either. Perhaps a qualitative statement could be made in the IA plan based on available literature, but without field tests by the PD contractor, we don’t see how we could report any test results.	
4	10	Table 1	Test 4: Please note that this effort should not be examining the national level impacts. That is being done by the DMA Program Evaluation Contractor. Instead, as stated in the TOPR, this effort should examine the “impacts of the two applications at various levels of potential future market acceptance on the **facility** where a small-scale demonstration of the prototype will be conducted.” Please fix.	Vasudevan	Thanks for the clarification. Text was modified as appropriate	

ID	Page	Section	Comment	Reviewer	Response from Contractor	Response Verification
5	10	Table 1	Test 8: Not sure where this one came from. Was this in the TOPR? I don't see a critical need for SPD-HARM or Q-WARN.	Vasudevan	This addresses the question in TOPR "Is Connected Vehicle Data required for Success" This question comes from the seventh bullet on page 13 of the TOPR, "To what extent are connected vehicle data instrumental to realizing a near-term implementation of the two applications?" We have replaced "instrumental" with "required".	
6	11	Cooperative Features	This page, entitled "Cooperative features" lists a number of assumptions regarding the responsibilities of FHWA and the PD Contractor. Have these groups agreed to these assumptions?	Hellinga	In short, "No." We can still conduct a valuable impact assessment without these "cooperative features", however; the assessment would be obviously not as complete. These assumptions were listed in both versions of the draft IA plan and no comments were received from FHWA or the PD contractor. We have not identified which aspects of the IA plan cannot be completed without these cooperative features. We are awaiting further input from the PD contractor as the PD work progresses.	
7	11	Cooperative Features	2f. and 2g. Why only for incident detection? Shockwaves and queues can form for recurring conditions as well. Please clarify.	Vasudevan	We were thinking of "incident" in the broadest context, to include queue formation itself as an incident, even if caused by recurring congestion. However, Text was modified to clarify that our intent is to include recurrent congestion	

ID	Page	Section	Comment	Reviewer	Response from Contractor	Response Verification
8	11	Cooperative Features	Third main item (please fix numbering). Comments applies to #2 and #3. Don't you also need additional data such as # of RSEs, locations of RSEs, # of vehicles with the capability, network files (e.g., GIS), information on work zones (if any), etc.? In addition, for #3 you will also need all the items listed in #2. Please check if this list includes everything you will need to model the prototype.	Vasudevan	Numbering fixed Thanks for the suggestions. In addition to RSEs, we also need information on other communication technologies employed on the facility, such as CMS. We agree. These items are part of the data for the test facility for the controlled/small scale test. We will review again the requirements for modeling the prototype when the details become available	
9	12	1.1	"The SPD-HARM application detects the presence of a mobility problem or predicts an imminent mobility problem…" I think it would be valuable to test the impact of a prediction component – with/without prediction. Or reactive vs. proactive. I don't see this reflect in the hypotheses anywhere though.	Colyar	We agree that it would be valuable to investigate the effectiveness of proactive vs. reactive SPD-HARM. However, this requires that a proactive algorithm is developed as part of the prototype, and we do not know the prototype details yet. This would add another dimension to the tests. We would need the PD contractor to develop two algorithms (one with prediction and one without), and we believe they are currently scoped to develop just one.	
10	12	1.0	Last line in first paragraph – please delete the parenthesis for DMA.	Vasudevan	Corrected	

ID	Page	Section	Comment	Reviewer	Response from Contractor	Response Verification
11	12	1.1	"A road weather information system (RWI) transmits facility information…" To what is the RWIS transmitting the information to? Please clarify.	Vasudevan	Corrected "transmits to TMC or directly to the equipped vehicles"	
12	13		Instead of relying on speed variances as a proxy for safety, the PD contractor could use eye tracking device to measure on- and off-target behaviors.	Bared	Certainly. The comment applies to the PD contractor. We believe this is not currently contemplated by the PD contractor.	
13	14	1.2	Why is the weather information not being used for Q-WARN if it is being used for SPD-HARM?	Vasudevan	That makes sense, seems reasonable.. This depends on the particular application/algorithm developed by the PD Contractor. We are conflicted here, trying to decide between describing in the IA plan what these applications could be, versus what they will be in the PD work. Our goal has been to describe those aspects of the bundles that are applicable to the IA plan, rather than providing a primer on SPD-HARM and Q-WARN	
14	15	1.3	3rd bullet – will the subject vehicle communicate with other vehicles about alternate routes or change lanes	Yousuf	It may. This depends to the particular application/algorithm developed by the PD contractor.	

ID	Page	Section	Comment	Reviewer	Response from Contractor	Response Verification
15	15	1.3	Last paragraph. To clarify, message stream from TMC will contain guidance that also includes information that there is a queue ahead. Need to provide reason to increase compliance. Why wouldn't the V2V message also include that the vehicle is "in queue"?	Vasudevan	Yes. Text was modified. The vehicle status, i.e., the speed may serve as an indicator that vehicle is in queue.	
16	16	1.3	Please fix the language here. I realize this is information I had included in an email to you where I was being colloquial – but please re-word. Thank you. Same comment applies to bulleted items on pages 12-13, and 14-15.	Vasudevan	Text was modified	
17	16	1.3	"The in-vehicle queue warning application is a reactive application (in my opinion)…" Who does "my" refer to?	Hellinga	Thanks for spotting this. Text has been struck.	

ID	Page	Section	Comment	Reviewer	Response from Contractor	Response Verification
18	17	1.4	"The impact is specific to the prototype being developed and not to the SPD-HARM and Q-WARN concepts and implementations." Is this what is required by this study? There is recognition that the prototype being developed as part of the PD contractor's work will have limited functionality. Consequently, some of the potential benefits of SPD-HARM and Q-WARN will not be achieved by these prototypes. However, the goal of the Impact Assessment is to determine the range of benefits that could be achieved through deployment of mature SPD-HARM and Q-WARN systems. By limiting the IA to the specific prototype being developed, it seems likely that the benefits will be under-estimated.	Hellinga	The TORP states that "the study will assess the impacts of a prototype of SPD-HARM and Q-WARN" It is not an open testbed of alterative concepts and prototypes of SPD-HARM and Q-WARN. Nevertheless, the IA assessment plan and findings in this study later on can be used as a framework to evaluate alternative concerts of SPD-HARM and Q-WARN in subsequent studies.	
19	19	2.0	"Loop detector data will be utilized…" This is correct, but when modeling please only model detectors that exist in the field.	Vasudevan	Clarification added to the text.	
20	19	2.0	"Recent statistical analyses of crashes…" Was this recent statistical work carried out by the IA contractor? If not, the text should identify and reference the work.	Hellinga	These findings have been reported in a number of studies. References have been added.	
21	19	2.0	"…bimodal distribution would imply…" Is this done by facility? And over what time duration?	Vasudevan	This is done on the test facility over the analysis period.	

ID	Page	Section	Comment	Reviewer	Response from Contractor	Response Verification
22	19	2.0	Suggest looking at the U of Minnesota ATM Effectiveness Report for ideas on MOEs. In particular, the report used “speed-based congestion” MOEs (a sort of proxy for showing effect on the speed distribution). This is related to your statement “In addition, we will use the data from all individual vehicles to develop distributions of speeds and headways…”	Colyar	We are trying to stick to the set of MOE’s identified in the ConOps for INFLO. But We thank the reviewer for bringing this recently published report to our attention[24] The speed-congestion MOE appears as a promising measure for SPD-HARM regarding distribution of speeds based on loop detector measurements instead of connected vehicles.	
23	19	2.0	What level of aggregation (time and space) will be done on the MOEs (e.g, 5 minute averages every ½ mile)?	Colyar	Please see also response to comment #24. We may use a finer resolution of aggregation on certain MOEs as described in the text (e.g., vehicles and headways at 0.1 intervals).	
24	19	2.0	Will some MOEs be reported on a lane-by-lane basis? Seems like this would be needed particularly for Q-WARN.	Colyar	Yes. In general, we will obtain the microsimulation output at the highest level of disaggregation.	

[24] Hourdos, J., et al, “Effectiveness of Urban Partnership Agreement Traffic Operations Measures in the I-35W Corridor,” Final Report CTS-13-22, University of Minnesota, August 2013

ID	Page	Section	Comment	Reviewer	Response from Contractor	Response Verification
25	20	2.0	First paragraph. It is proposed to use a “buffer” as a surrogate measure of safety at signalized intersections. This concept needs to be explained in more detail. How is this “buffer” measure similar to (or different from) other standard surrogate measures such as time to collision (TTC), deceleration required to avoid a crash (DRAC), etc.? Is there any evidence in the literature that (1) the proposed “buffer” is an appropriate surrogate measure of safety and (2) the value of “buffer” can be accurately estimated by the micro-simulation model to be used in the IA study?	Hellinga	This is a proposed approach by the research team to be investigated in the study in addition to the standard surrogate measures. These questions will be answered in the data analysis.	

ID	Page	Section	Comment	Reviewer	Response from Contractor	Response Verification
26	20	2.0	It is proposed to obtain “compliance rate” via driver interviews. How will this be done? What does the IA contractor actually mean by compliance rate? The contractor correctly identifies that compliance rate will be an input to the simulation model. Typically, we use the term “compliance rate” to reflect the degree to which drivers respond to the speed advisory. Essentially, this means that for a given speed advisory (say 40 mph); the simulation model needs to be provided with a distribution that indicates the desired speed of individual drivers. Some drivers with be completely compliant and will change their desired speed to 40 mph as advised. Others will completely disregard the advisory (totally non-compliant) and their desired speed will remain unchanged by the speed advisory. Others will be partially compliant (e.g. they may change their desired speed from 65 mph, when no speed advisory was given, to 55 mph when the speed advisory of 40mph is received). It does not seem to be possible to obtain these distributions from driver interviews so some additional clarification from the contractor is required as to what they mean by compliance; how they intend to measure it; and how they intend to model compliance within the simulation model.	Hellinga	Agreed. It is a complicated phenomenon to predict. We intend to assume different levels for the purposes of our simulation runs. Then when it comes time to make sense of the results our intent (as identified in Table 2) is to take advantage of any information developed by the PD contractor from its interviews of its test drivers to help get a better understanding of likely compliance rates and the conditions under which it occurs. This will permit the development of appropriate inputs for the simulation model.	
27	21	Table 2	How is “user acceptance” different from “compliance rate of speed” in Table 2?	Hellinga	Please see response to previous comment and comment #28.	

ID	Page	Section	Comment	Reviewer	Response from Contractor	Response Verification
28	21	Table 2	User acceptance – shouldn't this be if the user is satisfied that the advisory he got (expected conditions) matches the speeds he is able to travel at and what he observes (experienced conditions)? Is "desired" the same as above? Please clarify.	Vasudevan	Without a field test of unpaid users, it is not possible to directly measure user acceptance. The ConcOps proposed "percentage compliance with the recommended speed" as a measure of user acceptance. Since we will be inputting different assumed compliance rates in our simulation models we will not be able to directly measure compliance. As an alternative, we are proposing the difference between the driver's desired speed and the recommended speed as an indirect measure of user acceptance.	
29	23	3.0	Reference is made to varying geometric conditions including sight distance, vertical and horizontal curvature, lane widths, and shoulder widths. How will these conditions be captured within the simulation model? Is the model behavior actually sensitive to these conditions?	Hellinga	This paragraph is stating the likely factors influencing the need for and effectiveness of the INFLO applications. As pointed out by the commentator, Typically geometric features affect the capacity and free-flow speed of the facility. In microscopic simulation models their effect is captured through adjustments to car-following, lane preference and free-flow distribution parameters. We do not intend to examine geometric effects.	

ID	Page	Section	Comment	Reviewer	Response from Contractor	Response Verification
30	25	3.2	Question 2. When testing the communication method characteristics, please model what is observed for the PD effort. (i.e., for the first question in the TOPR)	Vasudevan	Perhaps we could use a little clarification on this comment. The IA contractor is not well positioned to conduct this test of the demand upon the cellular network imposed by the INFLO applications being developed by the PD Contractor. Our advice is for the PD contractor to measure the communication loads imposed by the algorithms on the cellular network in comparison to its capacity, and to determine the different latencies of DSRC versus cellular. We can report the results of the PD tests.	
31	25	3.3	"…benefits of national deployment…" Is this what is required from the IA study? I was under the impression that the assessment was to estimate impacts for a regional scale deployment. If so, then I would expect a number of different hypotheses to be considered to answer Question 3 (i.e. "What are the impacts of near, mid, and long term deployment?") For example, in the near term, the level of market penetration (LMP) of CV is expected to be low and that the LMP will increase over time. If benefits are expected to increase with increases in LMP, then assuming all other factors remain fixed, benefits are also expected to increase from short term to long term. However, it is likely that other factors will not remain fixed. For example, traffic intensity (demand to capacity) is likely to continue to increase over time. What about other factors such as increased cellular wireless speeds and lower latencies?	Hellinga	Thanks. See response to Comment ID #4. We will correct the text. Our focus will be facility only, not regional, not national. Please also see the discussion on page 26.	

ID	Page	Section	Comment	Reviewer	Response from Contractor	Response Verification
32	28	3.5	The treatment proposed by the IA contractor for effects of latency as an “either/or” problem seems to be a prudent approach.	Hellinga	We thank the reviewer No response is needed	
33	30	3.6	“How RSE affects the ability to inform unconnected equipped vehicles…” RSE has a specific meaning in connected vehicle research. These communicate only with “equipped vehicles and devices” and the center. If the intent here is to refer to other infrastructure based information dissemination methods (e.g., DMS/CMS/VMS), please use a different term. If not, please clarify.	Vasudevan	Indeed, the intent is to refer to other infrastructure methods (CMS). Text was modified as appropriate.	
34	30	3.6	“The examination would run the spectrum of potential RSE deployment, from 0% RSE deployment, **to detection deployment only, up to 1/3 mile spacing of detectors and changeable message signs**.” This is not clear. Please clarify.	Vasudevan	Text was modified. RSE spacing typical to fixed detectors of up to 1/3 mile”	
35	31	Figure 8	Is this a notional chart?	Vasudevan	Yes	
36	31	3.7	1st item under hypotheses – That doesn’t make sense. I think it might be a problem with terminology. Please see my earlier comment #29.	Vasudevan	Text was modified	
37	36	4.1.1	Are the references to “freeway” versus “highway” in the three bullets significant?	Hellinga	No. Replaced “highway” with "freeway” as defined in the first bullet.	

ID	Page	Section	Comment	Reviewer	Response from Contractor	Response Verification
38	36	Chapter 4	Maybe I missed it, but I don't see how long of a simulation period you are targeting (1 hr peak, 2 hr, 4 hr)?	Colyar	The length of the simulation period depends on the selected testbed characteristics. We will simulate the growth and dissipation of congestion on the selected facility	
39	36	Chapter 4	Maybe I missed it, but I don't see a calibration approach for the testbed. You'll select a testbed, then will you assume it's calibrated or do further calibration/validation? When will you know it's ready for use in the assessment?	Colyar	The selected testbed(s) are already calibrated and validated from previous studies.	
40	37	4.1.2	2 Testbeds are recommended – are you going to down-select to a single testbed at some point, or are you going to use both testbeds? If both, how will you decide which one to use for the 144 possible scenarios?	Colyar	We plan to select one test bed for the simulation experiments that would be different than the test site selected by the PD contractor for their tests. The final selection will be made once the details of the prototype algorithms are known.	
41	37	4.2	Is the contractor planning on using both VISSIM and AIMSUN?	Hellinga	One simulation model will be used. The final selection will depend on which of the APIs for connected vehicles available to the team for VISSIM and AIMSUN would faithfully replicate the prototype with a minimum of additional effort.	

ID	Page	Section	Comment	Reviewer	Response from Contractor	Response Verification
42	40	4.3	Guidance is stratified into 3 levels for SPD-HARM; low, medium, and high (in which each level is defined by a particular delta speed recommendation). It is not clear to me why the experimental design considers the delta speed recommendation as a control factor. Presumably, the speed recommendation is a function of the SPD-HARM algorithm and the prevailing traffic conditions. Thus, the delta speed will vary throughout the simulation as a function of the traffic conditions.	Hellinga	We agree. Page 41 of the draft IA plan states that "the guidance given by the algorithms will depend on the operating scenario under investigation. Thus we collapse the guidance dimension in the experimental plan”	

ID	Page	Section	Comment	Reviewer	Response from Contractor	Response Verification
43	40	4.3	I don't understand why you would include guidance as part of the scenarios. How can guidance be pre-determined? Shouldn't this come from the algorithms that you will get from the PD Contractor (which I presume will be interfaced with VISSIM)? The guidance will be a natural outcome of the scenarios. A related question – when you do the second half of what was called for in the TOPR to assess the regional impacts of the applications, is your intent to continue to model the impact of the prototype when deployed at a regional level? If the prototype assessment (the first question in TOPR) reveals that there are several limitations to the prototype algorithm (e.g., discrepancy between what the prototype detection algorithm says and what the simulation model visualization reveals), a suggested approach for the second question is to use other existing algorithms, such as the one developed by the STOL contractor or what the IA Contractor might already have.	Vasudevan	Please refer to the response to the previous comment #42, and the discussion on page 41. Given that the scope of work is to evaluate the prototype developed by the PD contractor, it is unclear to the research team the suggested approach to evaluate other algorithms at a regional level	
44	40	4.3	"Non-fixed point breakdown". It is proposed to model two levels of incident severity, namely (1) a single lane closure for 30 minutes and (2) a single lane closure for 60 minutes. This does not seem reasonable. What about incidents that block more than a single lane? I would expect that multiple lane blocking incidents tend to have a long duration than single lane blocking incidents.	Hellinga	Given the time and budget constraints of the study we plan to simulate scenarios with a reasonable expectation of occurrence. It is true that multi-lane lane blocking incidents last a long time and typically create excessive delays but their likelihood of occurrence is small, plus the effectiveness of the proposed applications is likely to be of limited benefit.	

ID	Page	Section	Comment	Reviewer	Response from Contractor	Response Verification
45	40	4.3	Facility characteristics – is this in addition to connected vehicles? Item b – do you mean facilities, such as arterials and rural roads?	Vasudevan	Yes	
46	41	4.5	What is the “systematic sampling” method? Why this is even required? How long a period is being simulated and what time of day will be modeled? How long will it take to carry out a single simulation run? I presume the post processing of the simulation data will be done through the use of custom programs/scripts so this should not be a limiting factor.	Hellinga	The text explains the process of systematic sampling. Please refer to the response to comment #38 on time period being simulated. Note that each test involves multiple simulation runs.	
47	43	5.1	Processing raw detector data. If data are obtained from a system such as PeMS, then data cleaning, etc. has already been done so no need to repeat this work.	Hellinga	Yes we do agree in the case of PeMS or similar data archival system. The text covers the general case that raw detector data from the demonstration site are provided to the IA team.	
48	51	B-3 C2	How will contractor model the existing 2013 speed advisory systems?	Hellinga	The revised IA plan does not include testing existing speed advisory systems	
49	59	B-3 C26	The contractor will collect weather data during the field tests, but how will the effect of different weather conditions (between the before and after periods) be considered?	Hellinga	We assume that the PD Contractor field tests will be performed under similar weather conditions.	

ID	Page	Section	Comment	Reviewer	Response from Contractor	Response Verification
50	61	B-3 C33	It is fine to indicate that diversion is not in the scope of testing. However, if the simulation network includes alternative routes, what will be done with respect to diversion? Will drivers have the ability to divert? If so, will this confound your evaluation? If drivers cannot divert, will this introduce unrealistic conditions that will adversely the estimated benefits?	Hellinga	This question can be fully answered when the details on the algorithm prototype and selected test bed become available.	

APPENDIX E: RESPONSE TO STAKEHOLDER COMMENTS VERS. 2.0

This section presents the responses to comments by the invited stakeholders on version 2.0 of the Impact Assessment Plan.

A total of 67 people were invited to participate as stakeholders in this project. The list of invitees was drawn from the INFLO Concept of Operations[25] and the Report on Stakeholder Input for INFLO report.[26] These two sources were augmented with additional suggestions from FHWA. These 67 people were contacted in December 19, 2013 and invited to participate as stakeholder reviewers of the Impact Assessment Plan. A reminder invite was sent out January 7, 2014. Twenty-one responded positively.

On January 11, 2014 version 2.0 of the Impact Assessment Plan was distributed to the 21 stakeholders for their review and comment with a deadline of responding by January 31, 2014. The following pages summarize their major comments and provides the research team's responses to these comments.

[25] "Concept Development and Needs Identification for Intelligent Network Flow Optimization (INFLO): Concept of Operations," Final Report FHWA-JPO-13-012, June 2012
[26] "Concept Development and Needs Identification for INFLO: Report on Stakeholder Input on Transformative Goals, Performance Measures and High Level User Needs for INFLO", Final Report FHWA-JPO-13-010, April 2012

RESPONSES TO STAKEHOLDER COMMENTS

Comment	Response
Bob Koeberlein – Idaho Transportation Department	
1. A table of acronyms would be beneficial. It is easy to lose sight of the points being made.	Agreed. Will add.
2. I think there needs to be assumptions concerning the class of highways that are likely to benefit from these applications. I think the answer should be freeways. Signalized arterials with coordinated (or adaptive) signal timing can accomplish speed harmonization by broadcasting (DSRC or cellular) the “green wave speed”. [I am assuming the traffic is flowing and not gridlocked]. I don’t think there would be much value in a more complicated approach. Queue warnings don’t seem too useful on slower speed signalized arterial highways, with typical signal spacing, where the drivers can usually see any queue in front of them. Also, queue length can change rapidly in a signalized setting. Telling drivers traveling through a congested signalized corridor something they already know will tend to condition them to ignore all the messages provided.	Agreed. The focus at this point is on freeways. We have dropped explicit references to testing the algorithms on arterials as part of the current project. However, the hope is to create a framework that can also eventually be applied to signalized arterials. We have clarified the text accordingly.
3. In section 1.1, I think the weather warnings generated from RWIS data elements need to include a grip value and the surface layer (these are available by deploying non-invasive pavement sensors). The pavement temperature can be below freezing and still have a safe grip value when there is no frost, ice or snow. Treatment chemicals also can affect the grip by melting ice and maintaining a liquid layer (and safe grip) at below freezing temperatures.	Thanks for the suggestion. Not clearly conveyed in the IA plan is that the algorithm will work with reported pavement coefficient of friction (rather than pavement temperature). We have clarified the text (See Appendix B in particular).
4. I envision a learning curve on the part of drivers regarding trusting the messages sent to vehicles. Initially there will probably be reluctance to believe the message until the driver can validate the message by observation. So the response rates may start low and increase with time and acclimation to the system by drivers.	Agreed. That is probably what will happen. We will be testing the effects on performance of different compliance rates, which can, as pointed out, vary over the life of the project.
5. Is identification of shockwaves widely understood? Maybe a definition would be useful?	Agreed, identification of shock waves is not obvious. Added definition to new section 2.1.
6. Figure 10, page 39, what are the units for the legend colors (i.e. 0-20 ____)?	We will add the units (they are “mph”).

Comment	Response
7. Page 40, Q-WARN, I would suggest you remove using the shoulder under "Medium". This could become a safety issue.	The Q-WARN prototype will not give guidance, so will drop reference to shoulder.
Steve Schladover	
8. Page 10 PDF (pg 8) - shockwaves will be too hard to quantify in number, duration or speed -- better to use a more aggregate measure of speed variability	Based on your advice we will use speed variance, an easier number to quantify.
9. Page 10 - Q-WARN doesn't affect queue length or duration, but only protects safety of vehicles approaching after the queue is formed	The thinking is that QWARN might cause some drivers to reroute. However, since we will not be testing route diversion, we will drop queue length and duration as a QWARN specific MOE.
10. Page 10 - These [proxy measures for safety] are too arbitrary to be meaningful surrogate safety measures. Better to not try to associate them with number or severity of crashes, which would be a huge stretch beyond validity.	Good Point. We will drop reductions in collisions and collision severity from the MOE's we produce, since our tool will be unable to reliably make that assessment.
11. Page 10 - How can a simulation produce a meaningful measure of this [compliance rate] relative to SPD HARM or Q-WARN?	Point well taken. We have revise text to state that we will NOT use simulation results to assess compliance rate.
12. Page 10 - RSE deployment should be irrelevant to these apps, which will be implemented using cellular technology, not DSRC.	One of the purposes of the Impact Assessment (IA) is to determine if RSE or DSRC are needed at all, given the widespread availability of cellular coverage.
13. Page 11 – How does the simulation represent inclement weather?	Current plan is to follow guidance given in Rakha, Zohdy, Park, and Krechmer; Microscopic Analysis of Traffic Flow in Inclement Weather (2010)
14. Page 12 - Don't claim anything on collisions [delta % collisions MOE] because the simulations can't produce any meaningful measure of that. It only destroys credibility of the project to make such claims.	Good Point. We will drop reductions in collisions and collision severity from the MOE's we produce, since our tool will be unable to reliably make that assessment.

Comment	Response
15. Page 12 - How are these simulations even representing differences based on whether V2V is available?	The plan is to build into the simulation certain random information loss rates for infrastructure detectors and connected vehicles. The more connected vehicles available, the more accurate and timely the information available for setting a recommended speed and warning of queues. The simulation however will not distinguish between how a vehicle receives its information (from the infrastructure or from other vehicles).
16. Page 15 PDF (pg 13) - The critical uncertainty for SPD HARM is the rate of driver compliance. How will this be determined in the experiment, based on naive test subjects from the general public? How will this avoid distortions based on subjects knowing that they are being observed in an experiment?	Our tool (and the small scale field test) will be unable to predict compliance rates, but we plan to test a range of compliance rates so that FHWA will be aware of what minimum compliance rates are needed to achieve a target performance improvement.
17. Page 15 - What's the mechanism for minimizing occurrence of bottlenecks? This looks like overselling.	The algorithm will not minimize the occurrence of initial bottlenecks. It will work by reducing the occurrence of secondary collisions related to the original bottleneck (whether due to incidents, weather, or recurring congestion)
18. Page 17 PDF (pg 15) - 511.org is specific to the SF Bay Area -- should be a more generic description here.	Reference to 511.org dropped.
19. Page 17 - If this [vehicle status] varies from manufacturer to manufacturer (as seems unavoidable) it will be very hard to get consistent, effective system management.	Good point.
20. Page 19 PDF (pg 17) - The prototype will inevitably be so small that it cannot have a significant measurable impact on traffic. Therefore the impact assessment will have to show negligible impacts. There has to be an approach to scale up to what a real system would do at full scale, otherwise why bother?	The intent of the Impact Assessment simulation model runs is to test the effectiveness of different scales of deployment.
21. Page 19 - What is the relationship of this prototype to the prototype speed harmonization that is being tested on I-66 under the STOL laboratory project? Will any synergy be sought between these projects?	Lessons learned from the STOL laboratory project are being carried over to the prototype development.

Comment	Response
22. Page 19 – [Collection of before and after data in the small scale demonstration] seems inconsistent with task descriptions below, so it's hard to tell what will really be tested and measured.	Details are being worked out by the prototype development (PD) contractor and FHWA.
23. Page 19 - Purpose of these [small scale demonstration] tests is not clearly defined -- what do you learn from the test results? If it's on a test track it tells nothing about traffic impacts, but only whether the data were transferred (which seems kind of trivial).	Details are being worked out by the prototype development (PD) contractor and FHWA.
24. Page 20 PDF (pg 18) - Those [USDOT affiliated sites] are DSRC testbeds, but these apps don't need DSRC so this seems an inappropriate restriction.	Details are being worked out by the prototype development (PD) contractor and FHWA.
25. Page 22 PDF (pg 20) - INFLO has been defined as a freeway app, not an arterial app, so why are signalized intersections being studied?	While INFLO currently is focused on freeways we would like the performance measure framework to be general enough to apply to signalized arterials in the future. We dropped signalized intersection text.
26. Page 22 - What is the representation of the INFLO apps that produces any such difference [in the driver's preferred buffer distance between vehicles] in the simulation? What do you change in the vehicle model for a vehicle that is equipped with INFLO?	We are looking into increasing the driver's target following distance and reducing the driver's target speed as the vehicle approaches the back of queue or in response to SPD-HARM message.
27. Page 22 - traffic simulations won't produce these output measures [max deceleration, speed gradient, time to collision] with sufficient fidelity to be useful for this.	True. We are just citing what had been used in the literature.
28. Page 23 PDF (pg 21) - none of these [performance measures in Table 2] will be measurable with any fidelity in a small-scale demo/test.	Yes. there will be challenges, and many may not be measured because of the challenges.
29. Page 27 PDF (pg 25) - When considering DSRC in the freeway environment, you have to think seriously about whether it's going to be affordable to provide continuous coverage. Even though DSRC latency is very short when you're in range of the RSE, it can become very long if you have significant gaps in coverage between RSEs.	Good point. We will take this into consideration in weighing our conclusions.

Comment	Response
30. Page 28 PDF (pg 26) - No [the message is eventually received, not lost all together] -- communication errors actually determine how much latency is experienced in receiving the messages. You keep sending updates repeatedly and if you lose some of those messages, the vehicles get them on later repeats.	Thanks for the clarification. We will revise text to clarify that message is eventually received, not lost all together.
31. Page 30 PDF (pg 28) – [modeling communication errors with simulation software like NS2/3 etc.] That is overkill for purposes of a study like this. You can handle this by representing communication latency and errors as additional delays in the information reaching the equipped vehicles -- much simpler to do an a lot more accurate representation of reality.	Thanks. We will do that.
32. Page 31 PDF (pg 29) - but the concept of a "deadline" doesn't really make sense in this concept. There is no specific cutoff time that distinguishes success from failure.	Thanks for the insight. We will take this into consideration. At this point our thinking is that latency is unimportant (the message eventually gets through), as long as the message gets to the driver in time. It seems to us that if the driver gets the queue warning after joining the queue, then the message arrived too late. But as pointed out by the commentator, perhaps the cutoff time is not so obvious for a SPD-HARM message.
33. Page 32 PDF (pd 30) - in-vehicle or roadside sensors? I don't see in-vehicle sensors helping at all for these apps.	The impact assessment is intended to find out if in-vehicle sensors will improve the operation of the apps.
34. Page 35 PDF (pg 33) - It's very hard to envision how cellular latency could be excessive for either SPD HARM or Q WARN, given that the cellular coverage is available.	The concern is about overloading the cell tower with messages (with the tower deferring transmission of some messages). This would be more critical for safety messages than mobility messages.
35. Page 36 PDF (pg 34) - Compliance rate is the one with the really large uncertainty, but the other two are straightforward (market penetration, comm loss).	Good point. We plan to test a range of possible compliance rates.

Comment	Response
36. Page 36 PDF (pg 34) - This [v2v increases the effectiveness of SPD-HARM and QWARN] seems highly questionable. You need to explain what the mechanism would be for V2V to increase effectiveness at the ranges and latencies associated with these apps.	The thinking is that at high market penetration rates, v2v might strengthen the effectiveness of SPD-HARM and Q-WARN, where adequate RSE coverage is lacking.
37. Page 36 - How will a controlled environment test produce any data to shed light on any of these three hypotheses [at the bottom of page]?	Correct. It will require microsimulation with some parameters suggested by the controlled environment test. We will revise the text accordingly.
38. Page 42 PDF (pg 40) - so this means you're not simulating steady state, but building up virtual queues at the upstream end of the mainline and on all the on-ramps? How do you account for those in assessing the results?	The plan is to accumulate delay for vehicles denied entry to the simulation facility because of queues backing up on the on-ramps or the mainline in. That delay will be added to the total simulated delay.
39. Page 42 - What parameters do you change in the simulation to "represent" these weather conditions?	We are working out the details. Current plan is to follow guidance given in Rakha, Zohdy, Park, and Krechmer; Microscopic Analysis of Traffic Flow in Inclement Weather (2010)
40. Page 42 – [for the simulation tests: road detectors will be] continuous in time or space or both? How close together would those detector stations be?	The infrastructure sensors should be continuous in time. We plan to test about ½ mile spacing of detectors. If resources allow, we might try different spacings in the simulation tests.
41. Page 47 PDF (pg 45) – Will there be test vehicles with data acquisition systems to record all these data [lag times, vehicle accel/decel, etc. from the controlled environment test], and who will reduce the data to manageable form?	We are working out the details with the PD contractor
42. Page 48 PDF (pg 46) – These [vehicle trajectory data and message logs for the small scale demonstration] again depend on having the appropriate DAS on the test vehicles	We are working out the details with the PD contractor

Comment	Response
Greg Larson - Caltrans	
43. Are you aware of the Networked Traveler – Foresighted Driving experiment that took place in the not too distant past, investigating the benefits of delivering a “slow or stopped traffic ahead” message to drivers upstream of a queue? [Here is the] link to the research reports: http://www.dot.ca.gov/research/researchreports/reports/2012/safe_trip-21/safe_trip-21_report.pdf. Pay particular attention to Track 3 and the reports on Disk 3. I think you might find the information on the experimental design quite useful.	Information much appreciated. We have downloaded a copy and reviewed it.
44. My main concern is that, as proposed, systems like these would open up infrastructure owners to additional liability: if the system does not work as advertised, we will be sued for damages. I think most agencies would rather not have that legal exposure, particularly when a third party could provide this service. Owning it ourselves would also mean additional components in the TMC (software, at the least), with the associated cost and complexity that are also a disincentive.	All good points.
45. I was also confused about the reference to arterials; to me, these are clearly freeway applications	Agreed. The prototype, in its current state, is suitable only for freeways. It is our hope though that it might be extendable, in the future, to arterials. We have cleared up the text to reduce the confusion.
46. . If we accept that premise, then the alerts should be delivered by cell phone, or some other method instead of DSRC, which will not be ubiquitous. These two applications will be most useful when the time horizon to an incident is relatively long, hence the “alert” rather than “warning”. As the time horizon approaches zero, V2V communications (DSRC) will take over, and the driver will be “warned” of an imminent crash.	Good points
47. Another consideration: at least our California Connected Vehicle Test Bed, and some of the others would not be suitable for demonstrating these two applications, since they are strictly built on arterials.	Agreed

Comment	Response
Tom Kurihara - Consultant	
48. I found the text interesting from a mechanistic and technological view, however, as a driver, I believe that there should be more reliance on increasing awareness of the operator and gauging reaction for early deployments and them progress the automatic control aspects as greater penetration of technology become a reality.	This is a good point, but resource limitations will prevent our proposed Impact Assessment Plan from being able to assess driver and public response (too many more fundamental technical deployment questions to be addressed first).
49. It is difficult to predict the balance between use of the allocated band for safety applications complemented with cellular technology, however [this will develop as] the cellular industry capabilities are rolled out.	Good point.
50. Profiles and optional technology introduction is important and should be more directly addressed by standards developers and included in the interface documents. My perception is that there is inordinate emphasis on design with limited optionality, leaving the detailed design and innovation to industry partners and service providers.	Correct. At this point the emphasis is on determining basic technical design questions.
Dennis Mitchell – Oregon DOT	
51. My remarks are more related to issues and concerns for discussion rather than specific comments on this draft. We are about to turn on a new system on 7 miles of freeway that includes variable advisory speeds (speed harmonization), queue warning and weather based variable advisory speeds. This is an infrastructure application with detection, speed signs and cms signs. The algorithms have already been developed and the software is being finalized to be activated within the next three months.	Thanks for the information.
52. Modeling is easier to differentiate alternatives but calibrating to real conditions is much harder. We think we will address safety issues and possibly some congestion, but the extent is unknown for sure. This will be a test for further deployment.	Agreed.

Comment	Response
53. One issue that came up relates to communication. These seem simple but need to be accounted for. One is the issue of having one controller per sign for each lane. When the system needs to change the speed on each sign the communication takes time so all signs may not change at the same time. Also which signs do you change first, nearer to an incident or farther upstream where the speeds are higher.	Thanks for this insight. We had been planning on assuming that all signs displayed simultaneously, but will look into how we might examine the issue of sequencing the displays.
54. Another is the smoothing of the raw data from the sensors. There will be a delay in reacting to an incident or congestion, since you need to average the data over a period of time so bad data does not make the system react erratically. There are also variables for minimum time before changing a message on a sign (different time periods for speeds decreasing or increasing).	Good suggestions. We will build these concepts (averaging to remove jerky responses, and minimum display times) into our testing protocol.
55. Are you going to model different reaction times between drivers (age, distracted, etc.)?	We will probably use the built in distribution of driver target speeds and preferred following headways (related to reaction times) in the microsimulation model, rather than do an explicit test of age and distraction effects.
Brian Smith – University of Virginia	
56. I think the plan is well thought-out and effectively documented. My major concern is one that you acknowledged – to truly assess the impact of these applications, you must have a sound understanding of driver behavior when using the system, and you need actual crash data. Unfortunately, neither is possible in a simulation test nor in a small scale demonstration. As such, I do think it will be important to present findings as potential benefits only	Agreed, we will talk about our findings as "potential benefits."

Comment	Response
Bill Legg – Washington DOT	
57. As you are probably aware the WSDOT has in operations three Active Traffic Management (ATM) systems on freeways in the Seattle urbanized area which provide motorists with legally enforceable variable lane-by-lane speed limits. The speed limits are adjusted based on prevailing traffic conditions including congestion and incidents and are adjusted automatically by an algorithm which bases decisions on a rich detector set. These ATM systems were specifically installed to encourage speed harmonization with the objective of increasing safety by reducing incidents. The systems also provide for lane-by-lane control to assist in traffic awareness and flow around incidents – the system opens and closes lanes based on conditions. The over lane signs are supplemented by full matrix DMS which providing messaging which supports the current speeds or lane restrictions so the drivers are aware of both the current travel rules as well as the “why” behind the rule.	Information appreciated.
58. These systems have been in operations 2+ years and we have substantial data about their performance – the Assessment Plan may benefit from looking at these systems and seeing what they have accomplished in terms of speed harmonization and safety therefore providing some “ground truth” to the planned project modelling as well as any planned test deployments in terms of what is expected vs. what is likely to be the result from a driver performance/compliance view.	The prototype speed harmonization algorithm, in fact, uses the Seattle methodology.
Eil Kwon – University of Minnesota	
59. It's a very well developed plan. The following minor issues are recommended to be addressed in developing the final plan	Comment appreciated
60. According to the proposed IA plan, the SPD –HARM would be ‘infrastructure-based’ and uses both nomadic devices and ‘VMS gentries’. The effects of different levels of gantry spacing on the effectiveness of the SPD-HARM could be interesting.	Yes. We hope to allocate some resources to testing different densities of infrastructure detectors and gantries.

Comment	Response
61. Three different levels (Low, Medium, and High) of Response Levels in terms of V2X penetration rates are going to be evaluated according to the IA plan. E.g., 'Low Level' assumes 0-10% penetration rate and 10% response rate would be assumed for this case. Does this mean 10% of vehicles with V2X capability would 'all comply' to the recommended advisory speed level?	We are intending to model different levels of the final result of a wealth of factors affecting compliance (market penetration, communication losses, etc.). We plan to test several levels of the percent of vehicles complying with the message. We then propose to post process the results to show how different combinations of market penetration and communication loss result in a net compliance rate.
62. It might be interesting to see how responsive the SPD-HARM and Q-WARN strategies are to the dynamically varying road/traffic conditions, e.g., how quickly they can identify 'bottleneck' locations/situations.	Yes. We do plan to test within our simulation environment the effects of different levels of sensor loss on the correct identification of events. However, the real world can, no doubt, produce challenges to detection we have not anticipated.
63. Many metro freeways have ramp metering systems in operation. The effectiveness of the SPD-HARM and Q-WARN strategies with/without ramp metering operations could be assessed.	Good point. We will look into that. We may not have enough resources to explicitly model this question, but we will try to address the potential impacts in our discussion.
64. The 'Guidance Level' is stratified into 3 levels in terms of the difference between recommended speed and prevailing speed levels, i.e., low (10 mph or less), medium (10 to 20 mph less than prevailing speed), high (25 mph or more). This is somewhat confusing, since the 'recommended speed reduction level' needs to be the output from the SPD-HARM strategy depending on the traffic/road condition.	Yes. This was some confused wording on our part. The severity of the incidents we test will vary, and the guidance will arise out of the specific incident. We will not arbitrarily change the guidance for a given incident. We will fix the text.
Darryl Dawson – Illinois State Toll Highway Authority	
65. Section 1.2 Q-WARN Application states that the INFLO Q-WARN application "aims to … minimize or prevent rear-end or other secondary collisions." Secondary crashes can be characterized as being in the same direction as the original crash or in the opposite direction. Clearly Q-WARN can address both situations. By slowing down traffic in both directions approaching a crash, it has the potential to reduce both types of secondary crashes, but likely will have a higher impact in the direction of the original crash. Secondary crash prevention should be predicted separately in each direction.	Agreed.

Comment	Response
66. As an infrastructure operator of an urban, suburban and rural Interstate highway, the Illinois Tollway is very interested in learning how much vehicle data is needed over what period of time to reliably detect and communicate the formation of queues. We assume that the Q-WARN app running in the vehicles approaching the back of the queue perform the primary queue "detection" and V2V communication, relaying the queue warning to other vehicles and infrastructure upstream of the queue. This relaying upstream is affected by the volume of traffic in each direction, which may be much different. In a sparsely travelled roadway, V2X would have to rely on vehicles travelling in the opposite direction to relay the warning to upstream vehicles and to the upstream infrastructure. The time it takes to propagate the warning back to the nearest DSRC RSE should be measured/predicted.	The controlled environment or small scale demonstration should provide some of the needed communication latency information, although daisy chaining of a specific message along a string of connected vehicles will probably not be explicitly tested. The microsimulation part of the impact assessment will conduct sensitivity tests on how RSE density and connected vehicle market penetration may affect the performance of the prototype.
67. Once the infrastructure is informed of the queue, its primary mission seems to be communication with the public through RSE dynamic signs, etc., and the determination of the "end" of the QUEUED state. No single vehicle can tell when the queue has ended – even in combination with others because it never can be sure to know about all other vehicles in the queue.	Agreed
68. The other interesting question for infrastructure operators like us is how to integrate legacy queue detectors (loops, radar, etc.) into the mix, especially in the early years of V2I deployment. However, that is far beyond the scope of this project.	We do intend to sensitivity test the effects of different mixes of legacy detectors and connected vehicles, but we will not be working on the how to make them work together.
69. Section 1.3 "Similarities and Differences" states that "device equipped vehicles will receive two streams of traffic information." One stream is from other Q-WARN equipped vehicles, and the other is from the TMC. It is not clear whether the study addresses performance degradation due to the delay or loss of communication from the TMC.	We will be doing sensitivity tests of the performance effects of communication loss, but we will not be predicting communication loss.

Comment	Response
70. Section 1.4.2 “Prototype testing by PD Contractor” Task 2 includes the development of detailed requirements including “Security”. If security requirements are included in the prototype demonstration, a means to validate security certificates will be needed. This may be a daunting effort, and may detract from the primary goal of demonstrating SPD-HARM and Q-WARN. If “Security” and/or other “support” functions are included in the demonstration, there should be some way to isolate their effect on the results, especially in the areas of lag time and message delivery reliability.	Good points.
71. CHAPTER 2. In the 3rd paragraph, 2nd sentence on page 19, should “extend” really be “extent”?	Yes. fixed.
72. CHAPTER 3. Section 3.2 Question 2: Question (2b) “When is DSRC needed and when will cellular suffice?” presupposes that DSRC is only needed in certain conditions. After operating a 62 mile long corridor under reconstruction with a combination of fiber in the ground and 4G LTE cellular, we have seen some of the drawbacks of the exclusive reliance on cellular communications for ITS applications. Many of our cellular reliability issues are not wireless issues. Instead they are within the cell carrier’s infrastructure. A tower could go off air, or, more commonly in urban areas, just become fully saturated with calls, blocking new calls from being accepted. Or there could be a problem in the carrier’s back office network infrastructure which relays digital packets to the customer’s data center. These types of “cellular” outages are more widespread, and of longer duration than a “wireless” reception issue, which usually clears up as the vehicle drives through the coverage zone of a single cell site to the next one. The “cellular” system outages vary in geographic range and in duration. These types of wider outages should be included in the model as discrete events – not just as the statistical combination of the communication loss rate with other factors, or the effect of these major cellular outages cannot be assessed.	Good Points

Comment	Response
73. Mainline queues lead to rear end crashes, which lead to secondary crashes. And they sometimes cause serious injury and death. The Illinois Tollway considers "queue detection" to be a "safety critical" function of traffic and incident management. It is now embedded into our integrated operational concept. And we do not trust such applications as V2I and ATM to cellular communication networks. But we understand that other infrastructure operators, due to cost, may have to do so. A cost/benefit analysis should be someday undertaken to determine whether the savings inherent in the utilization of cellular communication for queue detection is worth the lives lost resulting from widespread cellular outages.	Good Points about the tradeoffs between DSRC and cellular.
Juan Aparicio – Siemens Corp.	
74. Pg 8 – Compare Connected Vehicle based SPD-HARM with speed harmonization based on traditional ITS (e.g. Netherlands).	We are looking at options for combining traditional ITS with connected vehicles to provide a superior SPD-HARM result.
75. Pg 8 – to determine which communication method is best for nomadic devices need to identify measure of effectiveness of using different communication technologies.	The prototype tests will not be actually testing different communication technologies in the field, so we will not be able to directly compare comm methods.
76. Pg 8 – To determine effects of comm errors and latency, should consider different scenarios (mountain, tunnel, urban, etc.)	We will conduct sensitivity tests of various loss rates, but will not associate them to specific causes.
77. Pg. 10 – Why and what are the reasons that a large number of microsimulation model runs is not feasible?	Limited budget.
78. Pg 10, table 1 – Test 5 – Different SPD-HARM and Q-WARN strategies may be appropriate for different levels of market penetration.	Good point about different strategies being appropriate for different market penetration levels. We will however test only one strategy, the prototype, against different market penetration levels.
79. Pg 12 – How does SPD-HARM smooth traffic by lane.	Good point, the ideal is for SPD-HARM to smooth traffic speeds by lane with lower speeds for the right hand lanes. Overhead gantries with individual lane speeds can, in theory, achieve this, but customarily a single speed is displayed across all lanes.

Comment	Response
80. Pg 13 – How is compliance to be simulated?	We will do sensitivity tests of different levels of compliance, without predicting a specific level of compliance for the prototype.
81. Pg. 13 – Explain how compliance is related to the message content and lane by lane speeds?	The thinking is that if the driver understands better the reason he or she is receiving the message, and the advice is more closely tailored to the lane they are in, they will be more likely to comply. However, we have no data handy to support this supposition.
82. Pg. 15 – Elaborate on how the Q-WARN guidance is more complex than the SPD-HARM message.	The thinking is that the queue warning message will contain both distance to queue and the cause of the queue, and perhaps the delay associated with the queue. The speed harmonization message would be a simple recommended speed without explanation. However, other options are possible.
83. Pg 15 – Providing guidance on route diversion may be challenging. There are too many possible options. Providing only the "delay expected" may be enough.	Good point. Agreed.
84. Pg 14 – Why is weather information not used in Q-WARN application? Is not Fog a source of queues?	True. We have dropped this sentence from the document.
85. Pg 18 – It will be important to compute/answer: - How many RSE's per segment are needed? - How will these algorithms be integrated into today's TMC's? - How will these apps affect traffic control? - How many sensors/cameras are needed depending on penetration rate?	We hope to get the answers to most of these questions through sensitivity tests of different levels and combinations of RSE density, infrastructure detector density, and connected vehicle market penetration. The issue of integration with existing TMC's is deferred to future research.
86. Pg 20 – SPD-HARM and Q-WARN associated messages would impact other CV safety apps, like Signal Phase and Timing (SPaT). If more retransmissions are needed, it will overload the medium.	That issue is not one that we will be able to directly assess with the limited small scale demonstration of the prototype, but it is one of the issues with using these algorithms which we will bring up in the final assessment.

Comment	Response
87. Pg 25, Question 2 – How will you take into account future developments in cellular technology, e.g. 5G?	Good point. We will try to qualify our conclusions in light of potential technology improvements.
88. Pg 27, Question 5 – This section is not clear. How will these apps influence other CV safety and mobility apps? Retransmission may be harmful for safety aps.	Good point. See response to comment 86
89. Pg 28 – What is meant by V2X?	This was an attempt at a shorthand reference to both V2V and V2I. We will use V2X instead.
90. Pg 30 – Widespread roadside equipment (RSE) substitutes for V2V not cellular coverage.	Correct. We were misusing the term RSE in this section. Fixed.
Bob Burrows – G4Apps, Inc.	
91. Given the stated objectives of the study, the plan and performance measurements seem sound and have been reduced to a reasonable set in a well thought out manner. I agree with the causality tree including such steps as the inclusion of communications latency and loss as part of the part.	Comment appreciated
92. However I have an overall comment that I would like to make with respect to bringing the benefits of these applications to drivers and traffic in a safe, sound and well considered manner, given the situation today, as opposed to when the ConOps were developed. I recognize that this project is one step in a sequence that is already underway, and that USDOT may choose to continue consistent with that agenda. We will surely benefit from the efforts of this Assessment regardless.	OK

Comment	Response
93. The whole document and project seems to be constructed on the basis of DSRC and the formal connected vehicle technology and program – then cellular added later – with a good degree on interest but not without reconsidering from the ground up the objectives, timing and technologies that have the potential to bring a solution to the roads that may not be considered as technically precise as a DSRC based solution with DSRC RSE and 60% of vehicles participating 15 years from now, but which is actually more effective 3 years from now because it is good enough in guiding drivers in 99%+ of actual situations, even if it has a second or two more latency, but has 30%+ of drivers participating. This could be delivered using existing ITS including loops, radar, Bluetooth detectors and input directly from smart phones as probes or through services – then sent out to devices in vehicles via cellular.	Good Point. SPD-HARM and Q-WARN applications created for a cellular environment might have different features and requirements than ones created for a DSRC environment. This is an issue for the prototype developer. The impact assessment will evaluate whichever prototype is created by the prototype developer.
94. Nor does the study consider the use of in vehicle cellular based technology and app download capabilities that most automotive manufacturers will have on the road in 2014, including embedded WiFi. Nomadic devices, and in vehicle devices offer the technical capability to get large proportions of drivers to download applications immediately, in an opt in manner. The challenge then becomes ensuring that they have it turned on because they find it highly reliable. All technologies of course have the challenge of having drivers actually respond to any guidance because they trust it.	We will add these points and discussion to the impact assessment report.
95. I am not saying that the above solution is necessarily the right solution but it does have the potential advantage of having proportions of drivers opt in very quickly, to the extent that the statiscal processing of much larger volumes of data that individually be slightly less accurate in time and location actually make for a better, less costly and certainly earlier solution. I expect in any case that it would be a part of any longer term solution.	See above.
96. It has not been proven that 5% of vehicles doing things precisely can deliver better results than 30% of vehicles with less precise information, or that one with the other gradually increasing in participation isn't superior and more widely adopted and acted upon by drivers	Correct. We will see if we can answer this somewhat in our tests.
Morgan Balogh – Washington DOT	

Comment	Response
97. I read through the document. I don't have any comments. I do look forward to learning more about the algorithms that are going to be used.	OK
Mohammed Hadi – Florida International University	
98. Page 8 – Queue length should be performance measure for speed harmonization as well. It may have a positive effect and we should test it.	Agreed. Text fixed.
99. Pg 8 – throughput should be expressed in vehicles per hour per lane.	As a point measure of throughput, it would indeed be informative to use vph/lane. However, we will be reporting a system measure of throughput (VMT).
100. Pg. 8 – Reliability should also be reported for 80th % and 85th % TTI in addition to 95th %.	These measures may indeed be useful. At this point we would like to keep the number of performance measures reported as efficient as possible. If the 95th percentile behaves in an unexpected manner, then we would look a little deeper at the 80th and 85th percentiles.
101. Pg 8 – for crashes how are adjacent vehicles defined? What do you mean by crossing vehicles?	Yes. On further examination we are not going to use these particular measures of crash effects.
102. Pg 10 – Table 1 – Test 1 Objective: "than" not "then"	Thanks. fixed.
103. Pg 10, Table 1 – Delta crash severity in addition to delta collisions.	We have dropped analysis of likely crash severity and crash frequency.
104. Pg 10, Table 1 – for Test 7 and 8 will want to examine test 3 results as well as test 2	Added to Table 1 and 3.
105. Pg 19 – Data does not have to be limited to loop detectors.	Agreed. Revised text.
106. Pg 20 – The number of stops can also be a good measure of safety particularly for intersections	Agreed. In response to other comments about the algorithms being focused on freeways, we have dropped the intersection discussion.
107. Pg 21, Table 2 – see earlier comments on performance measures in the executive summary.	Table 2 revised.
108. Pg 23 – Question 1b - Should we consider weather conditions?	Yes. text edited accordingly.

Comment	Response
109. Pg 30, Question 6 - Some consideration should be made to situations were RSE equipment will have to be installed for other purposes at some locations and in these cases they can be used for other applications such as the ones addressed in this project.	Agreed. We will focus on identifying the RSE needs for SPD-HARM and Q-WARN, but other uses and considerations may support a denser installation.
110. Pg 36 – How can a freeway facility have intersections? Why do we call them freeways in the first bullet point and highways in the next two?	We are thinking of including in the microsimulation model the signals at the foot of the ramps. But yes, the freeway mainline will not have signals. We are talking only about freeways. Fixed text.
111. Pg 37 – FHWA has recently developed a DSRC emulator.	Yes. We have added it (TCA) to the text.
112. Pg 40 – What is the d/c level without incidents?	We will test two d/c levels for each scenario with and without incidents.
113. Pg 40 – Where are the DMS located? (how many and how far from the bottleneck)	We will test different densities of dynamic message signs, but resources will not permit us to be so precise as to locate them at explicit locations with respect to the bottlenecks.

APPENDIX F – RESPONSE TO COMMENTS VERSION 1.0

Deliverable Title: Impacts Assessment Plan for Dynamic Speed Harmonization with Queue Warning (V1.0)

Deliverable Date: September 5, 2013

Comments Date: September 24, 2013

Response Date: October 7, 2013

RESPONSES TO GENERAL COMMENTS

What is the proposed approach to combine operational, safety and environmental impacts? A straightforward additive approach might not work very well. Moreover, aggregate measures such as throughput per hour can be difficult to use for many scenarios since small improvements can just be due to stochastic fluctuations in demand or supply not necessarily INFLO. It would help to provide clear guidelines for the eventual use of data collected for all three impacts (operational, safety, environmental). (Kaan Ozbay, Noblis Team)

R1. Per discussion in our last meeting with USDOT, We will not be computing an overall composite safety/mobility/environmental index, not computing a benefit/cost ratio. If for some reason, the mobility, safety and environmental results are contradictory, the emphasis is on mobility.

Incorporating compliance rate into “tactical” decision making at each simulation time step is a challenging idea. At the strategic level say for route choice it is better studied. However, the case of “instantaneous or lagged” compliance with speed limit is more challenging, especially in terms of modeling a delayed response versus no response at all. Moreover, unexpectedly fast response to an instantaneous speed change can cause unwanted (maybe unrealistic) fluctuations in traffic for the simulation testbed. Safety implications of this situation can also be challenging to model and capture surrogate safety measures. Additional data from Europe or Japan where variable speed limits have been tested in simulation (implemented?) can be useful, if available. (Kaan Ozbay, Noblis Team)

R2. The comment confirms the difficulty addressed in the draft IA plan in accurately modeling compliance. Literature search is not in the scope but we will take advantage of readily available findings of relevance to the assessment.

The team has stated that this impact assessment plan will continue to be refined as more information regarding the PD contractor’s activities becomes available. Consequently, some of the specific comments may not be able to be address fully at this time. (Bruce Hellinga, Noblis Team)

R3. We appreciate the reviewer's understanding and we will update the document as appropriate as soon as new information becomes available.

As noted in the IA plan, we recognize that this is a preliminary draft, and will be refined as more information becomes available. Although the team has identified several hypotheses and discussed how these will be tested, a few critical hypotheses were missing from the IA plan. Here are some suggested hypotheses that you should include in your plan and test:

- Benefits will increase with increase in market penetration of connected vehicle technology.
- SPD-HARM and Q-WARN will yield more benefits when deployed in combination than in isolation.
- As communication latency increases, benefits will decrease.
- As communication error or loss increases, benefits will decrease.
- SPD-HARM and Q-WARN will yield more benefits under certain operational conditions.

Please expand this list. Please start with the research questions included in the TOPR, and identify one or more hypotheses for each question. This will help identify the analysis scenarios and structure the assessment process.

Secondly, although the IA plan included several elements of an IA plan (e.g., hypotheses, performance measures, assumptions, scenarios, market penetration levels, data QA/QC, etc.) the IA plan was missing certain key elements including: research questions, mapping of research questions to hypotheses, calibration approach, analysis scenarios (operational conditions + alternatives), and sensitivity analysis. It is understood that some sections cannot be discussed in detail without additional information from the PD contractor. However, it is good to include a placeholder and a brief discussion on what will be covered. (Meenakshy Vasudevan, Noblis)

R4. We created a new Chapter 2 in IA Plan.

It will be better to have section numbers in the document, makes it easier to reference. (Mohammed Yousuf, FHWA)

R5. Section # added

RESPONSES TO DETAILED COMMENTS

Id	Pg	Section	Comment	Reviewer	Response From Contractor	Ver
1	6	Intro.	Typo. “The prototype is being developed by the Prototype Development (PD) Contractor).” Please fix.	Vasudevan	fixed	
2	11	Hypothesis 1	The impacts assessment consists of (i) estimating the MOP for the roadway facility with the system (SPD-HARM and/or Q-WARN) operating and (ii) estimating the MOP without the system operating (i.e. legacy system). In the proposed IA, the legacy system is assumed to be a fully functioning circa 2013 ITS system. The plan describes the hardware components of the legacy system, including providing speed advisories on roadside CMS at one-mile spacing. It is necessary to also define the algorithms that drive the speed advisories as the impact of these speed advisories is highly dependent on the quality of the algorithm. Furthermore, this algorithm needs to reflect current “state of practice”. Hypothesis 1 mentions both penetration rate (i.e. the fraction of equipped vehicles in the traffic stream) and compliance rate (i.e. the fraction of drivers who travel at or below a posted speed limit or posted speed advisory). It is stated that a penetration rate of 50% and a compliance rate of 100% will be assumed. It would seem that a range of penetration rates must be examined in order to assess the impacts; however this should be easy to accomplish as the contractor will be able to control the penetration rate. Compliance rate is more difficult. There is evidence in the literature that compliance rate can have a large impact on the sign and magnitude of the impacts of various speed control systems. However, there is very little empirical evidence demonstrating driver compliance and therefore there is little evidence on which to make assumptions about driver compliance when carrying out the impact assessment. What is known is that compliance is highly influenced by the type and degree of speed enforcement. How will the IA address this?	Hellinga	A range of penetration rates will be examined as previously described in the response to general comment 4. Please also refer to the response to comment #13 regarding compliance rates.	

Id	Pg	Section	Comment	Reviewer	Response From Contractor	Ver
3	12	Hypothesis 1	Hypothesis 1: Proxy for crashes - How about using rapid decelerations or instances where maximum decelerations were applied as proxies? This may be used for both simulated as well as field data. If the PD contractor is able to provide some of the BSM Part 1 data, you could also look at the brake or ABS status.	Vasudevan	The suggested measures can certainly be used as proxies for crashes. We discuss this in detail in our response to comments #22, 23, 24.	
4	12	Hypothesis 1	MOE for safety can be quite difficult to quantify through field test especially for lower penetration levels where data to derive vehicle trajectories / individual vehicle interactions are not available. This is important because most of the surrogate safety measures are at the vehicle level.	Ozbay	No response needed	
5	12	Hypothesis 1	Please test the hypothesis for multiple market penetration levels. It will be interesting to examine at what market penetration levels (and compliance), connected vehicle technology starts to yield higher benefits than existing technology. This might differ based on the metric being studied. Please expand the plan to include multiple levels.	Vasudevan	We will test multiple penetration rates. Please see response to general comment 4	
6	12	Hypothesis 2	The term “performance elasticity” is not clear. Obviously, it sounds like it has a different meaning than its normal meaning adopted in the economic literature but I am not sure. It reads like the elasticity as a function of market penetration will change. I would like to think that “the value of elasticity” obtained from a given elasticity term will change. But I am not sure. This needs clarification.	Ozbay	The meaning here is that the improvement in performance to the change in market penetration depends on the level of market penetration	
7	12	Hypothesis 2	“mobility (throughput/time)” – Do you mean travel time? If yes, please fix.	Vasudevan	The meaning was (travel time, throughput) . Fixed	

Id	Pg	Section	Comment	Reviewer	Response From Contractor	Ver
8	12	Hypothesis 3	Hypothesis 3: The description seems to imply that there exists a single algorithm for each of the SPD-HARM and Q-WARN applications. Is this true? Is it not more likely that a different algorithm would be used when combining data from both fixed sensors and CV than when using data from only CV or only fixed sensors?	Hellinga	Variations of the SPD-HARM and Q-WARN algorithms may have to be developed given the data sources. However, the scope of the Impact Assessment is the testing the algorithm in the PD prototype. Not developing or modifying algorithms.	
9	12	Hypothesis 3	"…higher penetration rates of connected vehicles will provide the data required for the application without the need for data from the fixed infrastructure." The RSE can be viewed as a fixed infrastructure. Secondly, I don't think we know at this stage if we will not need any data from fixed infrastructure that are either part of connected vehicles or ITS systems. For example, will connected vehicle technology provide all the road weather data needed by the applications? How about archives of target speed recommendations and queue warnings or incident reports? These will help provide the reasoning for speed reductions or queue warnings to drivers. These archives will have to be stored somewhere, possibly at the Traffic Management Entity (TME), which I think would fall under the category of fixed infrastructure. Were you thinking of existing fixed sensors? Please clarify.	Vasudevan	The intent was to discuss the savings from fixed sensors. Text changed.	

Id	Pg	Section	Comment	Reviewer	Response From Contractor	Ver
10	12	Hypothesis 3	The following sentence, "Use of only connected vehicle data will enable the application without the need for ITS infrastructure which will facilitate deployment at lower costs," may not necessarily be true. The cost for deploying ITS infrastructure might reduce, but there is still the cost for deploying connected vehicles. At this stage it is unknown what the market penetration levels should be for connected vehicles (e.g., integrated vehicles, RSEs, nomadic devices, communications) to yield significant benefits. This impacts assessment study, the IA studies being conducted by the other bundles, and the AMS testbed effort will all help inform us on what penetration levels are the most cost-beneficial.	Vasudevan	We agree Text modified	
11	12	Hypothesis 3	This hypothesis can be tested by assessing what the prototype did and how well the algorithms performed. In addition, you might want to interview/survey the prototype developers what they perceive are useful data based on their experience with the prototyping effort. The same question may also be asked of other stakeholders involved with the prototype demonstration and impacts assessment efforts.	Vasudevan	Text added	
12	13	Hypothesis 4	Although the hypothesis listed here may be used as assumption, there needs to be a separate hypothesis which specifically looks at the impact of market penetration-compliance levels on the system benefits. You may also examine the benefits under various operational conditions and various communication latencies, errors, etc. The team may want to assess and propose the extent of communications modeling that can be done within the available resources.	Vasudevan	Please refer to the response to general comment 4.	

Id	Pg	Section	Comment	Reviewer	Response From Contractor	Ver
13	13	Hypothesis 4	Hypothesis 4: My comments related to Hypothesis 1 might be better addressed to Hypothesis 4; which in this case is actually an assumption being made by the contractor. The assumption made is that two conditions are equivalent if the products of penetration (P) and compliance (C) are equal (i.e. for two conditions A and B, if PA x CA = PB x CB, then these two conditions are equivalent). This is a strong assumption. Is there any basis for this assumption? Given the influence that compliance can have on the performance of speed control/advisory systems, this assumption my strongly influence the IA results. In the absence of a justifiable basis for this assumption, this assumption may undermine the level of confidence that can be placed in the IA results. Can the contractor conceive of ways in which driver compliance data could be obtained from: (i) existing field data for calibration of the simulation model and/or (ii) data collected from the controlled or field test for the purposes of validating assumptions or calibrating new compliance models. If no evidence can be obtained to support an assumption about compliance, it would seem appropriate to determine the sensitivity of the system performance to different levels of compliance. This would provide an understanding of the performance impacts across a range of driver compliance behaviors and may be valuable in determining how critical high levels of compliance may be for achieving benefits from the SPD-HARM and Q-WARN systems.	Hellinga	We agree that is a strong assumption but it is very difficult to accurately model compliance causes as we explain in the text. Data from the field test will involve only a few drivers of which a small sample of them may provide evidence of non compliance. We can certainly perform sensitivity analysis assuming a range of compliance rates for each penetration rate. We discuss this option in our original text of estimating impacts of market acceptance. We expand on this in response to general comment 4.	
14	13	Hypothesis 5	This may be tested by interviewing/surveying the prototype demonstration or test drivers about the devices and messages. Please see question #4 in the FRATIS IA questions that I sent previously. The assessment can be made based on drivers' perception of benefits and their experience. Even if the hypothesis testing is not conclusive, you can make an assessment if the hypothesis was validated for the demonstration. Please move the hypothesis from the assumption section to the "will test" section.	Vasudevan	We moved the hypothesis to the "will test" section. We added the option of interviewing drivers with sample questions.	

Id	Pg	Section	Comment	Reviewer	Response From Contractor	Ver
15	13	Hypothesis 5	Hypothesis 5: This sounds like a good assumption for the field test. It is little more complicated when I think of the speed variation obtained from a simulation since there is really no way to claim that the car following or lane change model in a simulation reflects the behavior of an individual driver in terms of “distraction.” This kind of assumption can underestimate the effect of “distraction” because inherently majority of car following algorithms do not necessarily do a great job in capturing realistic driving behavior of individual drivers and driver distraction.	Ozbay	Please see the updated text in response to the comment #14.	
16	15	Table 1	In the case of using simulation, simulation model has to be calibrated not just to reflect the agreement of the simulation model with operational parameters (speed, flow and density) but also with safety related parameters. There are several recent papers that discuss novel approaches to achieve this type of multi-objective calibration, including one that I co-authored: Hong Yang and Kaan Ozbay. Calibration of Micro-Simulation Models to Account for Safety and Operation Factors for Traffic Conflict Risk Analysis. In the Proceeding of 3rd International Conference on Road Safety and Simulation, September 14-16, 2011, in Indianapolis, Indiana, USA. Available: http://onlinepubs.trb.org/onlinepubs/conferences/2011/RSS/2/Yang,H.pdf	Ozbay	Model calibration for safety related parameters does require vehicle trajectory data of ALL vehicles as described in the referenced paper. Such data are not available with the exception of NGSIM data used in the paper	

Id	Pg	Section	Comment	Reviewer	Response From Contractor	Ver
17	15	Table 1	It is not clear how the sensor data will be used to collect accurate shockwave information (number, propagation speed, etc.). This kind of information cannot be easily collected using any configuration of point detectors and there will be a need for some kind of spatial data collection (unless there is a plan to use some kind of off line estimation based on limited point data). It might make sense to think about other ways of collecting real-world data) other than or in addition to loop detectors) during the actual field testing. INRIX data is mentioned on page 17, but one has to be careful about its accuracy and availability. This needs more clarification since this is one of the most crucial aspects of this effort.	Ozbay	Please refer to the response to comment #19. INRIX data was mentioned as an example of alternative data source. Its usage depends on the accuracy and completeness of the data.	
18	15	Table 1	Was the plan for your team to collect loop detector data? Were you planning on collecting it for the demonstration site, if the PD contractor is asked to conduct a small-scale demonstration? Please confirm with the PD contractor if they will provide you with the data you have listed, at what granularity, on what facilities, and how often. Is there any plan to collect supplementary data such as weather, incident reports, and other data that are not given to you by the PD contractor?	Vasudevan	As described in the Section "Data Expectations from the PD Contractor ", such data are expected to be provided by the PD contractor	

Id	Pg	Section	Comment	Reviewer	Response From Contractor	Ver
19	15	Table 1	Can shockwaves and queue lengths be accurately estimated using loop detector data? You can supplement the data that you get from the vehicles with the data from the loops, to calibrate the simulation model and assess shockwave and queue length formation, propagation, duration, and location. Was that the intent? If yes, please leave as is, although it might help to include a couple of sentences on how loops might be used to detect shockwaves and queues. Otherwise, please clarify.	Vasudevan	Text added. The primary source for shockwave and queue length estimates is the simulation model outputs. However there are procedures based on loop detector data to identify bottlenecks and related congestion characteristics.	
20	15	Table 1	In Table 1, how will the results from the simulation model be used to measure the “compliance rate of speeds”? Presumably, compliance rate is something that must be provided to the simulation model as an input.	Hellinga	Yes, the compliance rate is an input to the model. Table 1 corrected	
21	15	Table 1	In the simulation, what will be the assumptions / models to generate emission estimates? What kind of sensors will be used to collect emission data? Or is this going to be derived from a model?	Ozbay	Fuel consumption and emission estimates will be outputs from the simulation model. We will document the assumptions and models used.	

Id	Pg	Section	Comment	Reviewer	Response From Contractor	Ver
22	15	Table 1	Table 1. Proxy measures for safety can be improved. There are several recent papers that are more advanced than the simple threshold based measures given in Table 1. For example one recent improvement is to use surrogate measures that can combine speed difference with actual speed and or acceleration/deceleration rates. I suggest that the team reviews some of the more recent papers and update this section with more detail.	Ozbay	We added text and references in the text regarding surrogate measures for safety. We have not selected final proxy measures yet pending additional information on the prototype.	
23	15	Table 1	Proxy measure for crashes - # instances where adjacent veh speed diff > 10 mph. By adjacent vehicles, do you mean within lanes, across lanes, or both? Is this an arbitrary number or already researched thoroughly? If yes, please include reference. If arbitrary, will you be doing a sensitivity analysis by varying this threshold? Same comment on the proxy for severity of crashes.	Vasudevan	We mean within a lane. This is an “arbitrary number” at this point. Please refer to response to comment #22 regarding selection on proxy measures and the modified text in the document.	
24	15	Table 1	In Table 1, is there a basis for the proposed proxy measures for number of crashes and severity of crashes? Given that these proxy measures will be extracted only from the simulation model, a wide range of proxy measures (or safety surrogates as they are often referred to in the literature) could be used. There is a considerable body of literature related to various safety surrogates and it would be valuable to make reference to this work in selecting/proposing the safety surrogates to use for the evaluation.	Hellinga	Please see response to comments #22 and 23.	
25	16	Table 1 discussion	Typo in 3rd bullet. Please change to “inclement weather…”	Vasudevan	fixed	

Id	Pg	Section	Comment	Reviewer	Response From Contractor	Ver
26	16	Table 1 discussion	When collecting data from a field test, how will the influence of weather be considered (or controlled for) within the evaluation?	Hellinga	Data on weather conditions will be collected during the field tests	
27	17	Processes for Verifying Data Quality	"We will apply standard techniques for loop detector data checking, cleaning and filling missing." What are considered standard techniques? Please elaborate.	Yousuf	Text added in the document to explain the techniques mentioned.	
28	17	Processes for Verifying Data Quality	This is a very generic discussion that can be improved. I guess it makes sense to wait for more details to become available before doing that. One question that can be addressed here is what the back-up plan is if the data quality / availability is not at the minimum desired level. Is there a plan to install additional and /or new sensors?	Ozbay	It is difficult to provide additional information without knowing the prototype and the site for the field tests.	
29	17	Processes for Verifying Data Quality	Why was it decided to aggregate the data to 5 or 15 minute-intervals? Is that sufficient granularity for detecting shockwaves and queue lengths? Or is the aggregation being done only on loop data for use as input to your simulation models? Please clarify.	Vasudevan	Text added. The aggregation is done to the loop detector data for input to the simulation models, and for characterization of operating conditions.	
30	17	Collecting Feedback from Stakeholders	Good to see a section on this. The feedback can be used to test some of your hypotheses that you were planning on testing using simulation outputs. You could structure the questions based on the hypotheses that need to be tested.	Vasudevan	Agreed	

Id	Pg	Section	Comment	Reviewer	Response From Contractor	Ver
31	17	Collecting Feedback from Stakeholders	What is the planned sample size for these interviews / feedback? In my experience, one can design the app to be deployed with nomadic devices to get the feedback automatically about usage / reliability / latency / errors almost without any direct user involvement. For other feedback individual interviews / focus groups / questionnaires might be required. However, it is important to get this feedback in a timely manner to avoid biases and errors due to forgetting etc.	Ozbay	This is valuable input for the PD contractor in case a nomadic device is employed. Text was added. We will expand this section including sample size requirements once additional information about the prototype becomes available.	
32	17	Collecting Feedback from Stakeholders	It is suggested that surveys of drivers will be conducted to assess driver compliance. This requires additional thought/detail. Will these surveys be done after a trip is completed and ask the driver if they complied with the posted speed advisory? How accurate would you expect this to be? Would it be possible to directly measure the vehicle speed along with the recommended speed and determine compliance?	Hellinga	It appears possible to directly measure the vehicle speed from the instrumented vehicle trajectory through the Basic safety message (BSM) and compare with the speeds recommended by the algorithm.	

Id	Pg	Section	Comment	Reviewer	Response From Contractor	Ver
33	18	Simulation testbed Selection	The work plan recommends two simulation testbeds; US 101 and I-210. There is mention that the US 101 site may be extended to include a parallel arterial. In this case, diversion from the freeway will be possible and will be (can be) captured within the model. How will this influence the evaluation of the SPD-HARM and Q-WARN systems? If a parallel arterial is not included in the testbed then diversion will not be possible. How will this influence or limit the evaluation?	Hellinga	Diversion is not in the scope of testing SPD_HARM and Q-WARN prototypes	
34	20	Estimating the Impacts of the Prototype Demo/Test	I understand that the research team has APIs for simulation of V2V and V2I communication scenarios. It will be useful to clearly explain / describe how these APIs match hardware and software specifications of their real-world counterparts. For example how well are the emulated WiFi and other wireless communication protocols? What are the main assumptions of these APIs in terms of bandwidth and channel usage protocols for different devices especially at high market penetrations where there might be less capacity then demand, etc. Moreover, it might more be important to model these communication protocols accurately for safety related performance measures where the effect of packets dropped or high latency have to be captured.	Ozbay	See lengthy response at end of this table	
35	20	Estimating the Impacts of the Prototype Demo/Test	Please note that the USDOT INFLO study is not focused on Q-WARN, but the PD effort will produce Q-WARN algorithms, which will be shared with you.	Yousuf	No response is needed	
36	21	Operating Scenarios	What was the logic behind the selection of levels for the experimental design proposed for simulation based operational analysis? Is it based on actually observed data / incidents at the test site(s)? Some kind of connection to real-world data might help to correlate field results with simulation results.	Ozbay	The levels selected illustrate typical conditions of recurrent congestion and incident severity. They may be refined later when the test sites are known.	

Id	Pg	Section	Comment	Reviewer	Response From Contractor	Ver
37	21	Operating Scenarios	Why only consider rainfall in the weather scenarios? It appears that a total of 18 experiments are proposed (4 associated with recurrent congestion, no incidents, and clear weather; 12 associated with non-recurrent congestion and clear weather; and 2 with inclement weather although the d/c ratio is not specified). Is there any intention to consider the interaction effects (e.g. inclement weather and an incident, etc.)?	Hellinga	Yes, a combination of conditions will be tested. This is explained in the revised text and addressed in response to general comment 4	
38	21	Operating Scenarios	"Weather related breakdown: Inclement weather rain intensity.." how about other road conditions, fog, back ice, snow etc.?	Yousuf	We included these conditions in the proposed simulation testing. Please see revised text	
39	21	Operating Scenarios	These are discrete operational conditions. How about combinations of the above? How about variations in travel demand? These might need to be ironed out after seeing what the PD contractor will be demonstrating and where. For the second simulation model you could pick the operational conditions that are not covered by the demonstration site. Please identify the critical operational conditions (i.e., not just the three but also combinations), which can be prioritized based on discussions with USDOT. Also, hopefully the levels you identified are illustrative since it is best to use field data to drive these thresholds. If not illustrative, please clarify reasoning.	Vasudevan	We will test combinations of operating conditions including demand variations described in the revised text, and response to general comment 4. The threshold of operating conditions are indeed illustrative.	

Id	Pg	Section	Comment	Reviewer	Response From Contractor	Ver
40	21	Operating Scenarios	What you have here are operational conditions. How about the alternatives that will be simulated and tested? The PD contractor will not be demonstrating every alternative, but the IA effort should simulate ones that are high-priority ones. Please identify research questions and the corresponding alternatives that will need to be modeled. For example, to examine the following research question in the TOPR, “What are the benefits of widespread RSE deployment versus ubiquitous cell coverage? Which is more beneficial? What is the marginal benefit with data from existing sensors?” you might have to model an alternative that only makes use of cellular communication, a second alternative that only makes use of DSRC-based communication, a third that makes use of cellular and existing sensors, a fourth that makes use of DSRC and existing sensors, and so on. This can easily get out of control, but it is good to use a systematic approach to enumerate the alternatives, which can then be prioritized based on discussions with USDOT.	Vasudevan	Our original document covered the testing of the prototype (including communications) built by the PD contractor over a range of operating conditions. We have included the modeling of alternatives mentioned in this comment in response to the general comment #4 , subject to discussions with USDOT on the extent of communications modeling.	
41	21		How many repetitions of each simulation run will be conducted? What methods will be used to statistically assess simulation results?	Hellinga	We will follow the guidance in FHWA’s Traffic Analysis Toolbox Vol III “Guidelines for Applying Traffic Microsimulation Modeling Software”	

Id	Pg	Section	Comment	Reviewer	Response From Contractor	Ver
42	22	Estimating Impacts of Levels of Market Acceptance	Are the market penetration levels that are identified applicable across all vehicles types? Please note that in the ConOps the near, mid and long term definitions included market penetration for specific vehicle types. Will that be captured? This is another one where some prioritization can take place to reduce the number of runs.	Vasudevan	Indeed the ConOps differentiate market penetration levels across vehicle types. We will investigate this per response to #4.	
43	22	Data to Be Shared On the RDE and PII Data to Be Protected	"What data elements are proprietary or include personal identifiable information (PII)…" would we know enough to identify PII from the available data sets?	Yousuf	We cannot address this at this point because we have no knowledge of the prototype and the associated inputs/outputs	
44	22	Data to Be Shared On the RDE and PII Data to Be Protected	In the INFLO SOW page 6, there is a discussion of open sourcing which might be useful to mention in this section of data requirements along with some mechanism to ensure access by others.	Ozbay	Addressed. Please see next comment	
45	22	Data to Be Shared On the RDE and PII Data to Be Protected	Please move the following sentence, "We will make the impacts assessment methodology and supporting code (e.g., spreadsheet files, database queries, analytical tool input and output files,) and API(s) developed under this project." To a separate section on "Methodology and Code on OSADP" or redo the title of the existing section to include OSADP as well. Secondly, please fix the sentence by adding the following, "…available as open source on the OSADP."	Vasudevan	Text modified per comment	

Id	Pg	Section	Comment	Reviewer	Response From Contractor	Ver
46	22	Data Expectations from the PD Contractor	For the CET, it will be useful to mention how the driver specific data such as “driver reaction time” and “driver perception time will be collected”. Are they also collecting driver data such as age, gender, previous driving history, etc.? If so, this can be a rather limited sample size which will limit field testing of different market penetration levels.	Ozbay	We do not know this information at this point. Please note that field testing of different market penetration levels is not in the scope.	
47	23	Data Expectations from the PD Contractor	4a. “Calibrated Microsimulation Model for Before Condition….” Is this supposed to be provided by the PD contractor?	Yousuf	This is a presumption on our part.	

RESPONSE TO COMMENT #34 (OZBAY)

The research team has two APIs tested with operational microsimulation models; one developed by the University of Arizona for the VISSIM model that provides the basic safety message BSM, and one developed by ITRE at NC State for the AIMSUN simulator.

Information about these APIs is given below.

ITRE API

The ITRE v2v communication module works as an add-in to the Aimsun simulation package. It simulates inter-vehicular communications with the same simulation step (between 0.1 and 1 second) as Aimsun simulates vehicle movements. The Aimsun simulation engine updates vehicle movements and computes everything once every simulation step. Inter-vehicle communications are therefore updated once every simulation step too, while in reality communications can happen at any time during this step time interval (say, 0.1 seconds).

It is assumed in the ITRE v2v module that any two v2v-equipped vehicles can communicate with each other as long as they are within a certain distance (say, 500 meters, computed based on the coordinates of the two vehicles) and data package transmittals between the two vehicles are always successful. The ITRE v2v module currently does not simulate any real communication protocols, such as Dedicated Short Range Communications (DSRC). To simulate those protocols, the simulation software has to be event-driven, which simulates each and every event involved in the communication protocols and can trace and analyze events at any time point. All the popular communication simulation packages that we are aware of are event-driven, such as NS2, NS3, and OMNet++. Simulation of communication channels, channel usage, and bandwidth are all available in these packages. One communication event using protocols like DSRC only take a few nanoseconds to complete. The 0.1-second simulation step of traffic simulation packages is therefore way too long to take channel usage and bandwidth into account with any realistic meaning.

There have been experiments and practices that marry time-driven traffic simulation packages with an event-driven communication simulation packages to make the v2v simulation more sophisticated and realistic. Some of those integrated packages are listed and briefly described in our proposal. For example, Jist/SWAN developed by Michael Zhang of the research team can simulate latency and interference and be used to develop/test communication protocols. VGSim uses DSRC / WAVE protocol.

As the ITRE v2v communication module currently stands, a more realistic improvement that can be made without big difficulties is to add the capability of simulating signal (data package transmittal) losses based on the distance between two connected vehicles using Nakagami Distribution (wiki). This distribution assumes that signal reception decreases with distance increasing. This distribution is widely used in the wireless communication field.

UA API

Implemented equipped vehicles that broadcast Basic Safety Messages that contain GPS position data, speed, acceleration, status of braking system, etc... The external components can be a hardware of virtual OBE and a hardware of virtual RSE. OBE's can communication with each other or with the RSE. Vehicles can send other J2735 messages including Signal Request Message and can receive messages such as Signal Status Messages. Other messages are easy to add and the driver behavior can be modified to include change in speed, lane, etc. Will work with any network that is or can be modeled in VISSIM. The market penetration can be varied by generating different distributions.