Subject:	From:	Date:
2019 INFRA Grant BCA – COAST	**Florida Department of Transportation**	**02/11/2019**

Introduction

This document serves as a technical memorandum to explain the procedures used to complete the benefit-cost analysis (BCA) for the Florida Department of Transportation (FDOT) 2019 INFRA Grant Application for the Connecting Overseas to Advance Safe Travel (COAST) project. All the assumptions and methodologies used to produce the analysis are outlined in this document. The expected benefits and costs of the Connected Vehicles (CV) deployment along the U.S. 1 corridor from Key West (Mile Marker 0.0) to Key Largo (Mile Marker 112.5) are identified and compared. This technical memo along with the spreadsheet presents the calculations and describes the analysis in detail. While preparing the BCA, different impacts of CV deployment on the infrastructure are identified. The BCA outlined in this memo is consistent with the United States Department of Transportation (USDOT) guideline[1] published in December 2018.

Overview

The COAST project would be deployed in the year 2020 and the service life of the deployed CV infrastructure would be 20 years from 2020 to 2039. The analysis period considered for the BCA is 20 years, as well with 2017 being the baseline year or the no-build alternative scenario year. To account for inflation in the future years of operation, discount rates of three percent and seven percent are assumed. This discount rate is applied to the operation & maintenance costs as well as the benefit costs. The average travel speed of vehicles on this corridor is 46 miles per hour (mph) and it is assumed that the market penetration of CVs would be 30 percent over the 20 years of operational analysis. The trip length is assumed to be 56.25 miles, which is 50 percent of the length of the corridor. There are additional savings in travel time for freight and emergency vehicles due to weigh in motion (WIM) and pre-empts respectively. The baseline crash risk is one, which suggests that the future year crashes would be the same as the average annual crash from historical data in the baseline year.

Deployment Costs

The CV infrastructure would be deployed in 2020 and the base year for the deployment cost and the previously incurred cost (shown in Table 1) of $9.32 million estimations is in 2017.

Table 1. Deployment cost distribution

Item	Description	Unit	Quantity	Unit Rate	Total Cost
RTMC Upgrade	Deploy ATSPM at RTMC and Configure Signals	LS	1	$ 60,000	$ 60,000
	Vendor API for CV Data - SPaT NTCIP to SAE and Mapping	LS	1	$ 50,000	$ 50,000
	Storage/Server Upgrade for ATSPM and CV Data	LS	1	$	$ 100,000

[1] https://www.transportation.gov/office-policy/transportation-policy/benefit-cost-analysis-guidance-2017

	Security Credential Management System	LS	1	$ 50,000	$ 50,000
Field Upgrades	Traffic Signal Assembly Upgrade (w/2070 LX Controllers), F&I	EA	8	$ 50,000	$ 400,000
	Traffic Signal Assembly Upgrade (w/1C Card), F&I	EA	17	$ 1,200	$ 20,400
	MFES for Traffic Signals, F&I - (Traffic Signals, Emergency Signals, PHBs)	EA	44	$ 2,500	$ 110,000
	Police Panels, F&I	LS	1	$ 60,000	$ 60,000
	ITS CCTV Camera, F&I - (Traffic Signals, Emergency Signals, PHBs)	EA	46	$ 15,000	$ 690,000
	City of Key West Signal Upgrades (UPS, APS, SOP rewire, Police Panel)	LS	1	$ 600,000	$ 600,000
	Cradlepoint IBR1700, F&I	EA	25	$ 2,000	$ 50,000
	Conduit, F& I, Aboveground (50 LF)	LF	1500	$	$ 37,500
	Conduit, F& I, Directional Bore (2 runs of 75 LF)	LF	5000	$	$ 150,000
	Conduit, F& I, Open Trench (4 runs of 50 LF)	LF	6500	$	$ 78,000
	Loop Assembly - F&I, Type A (6 loops each)	EA	195	$ 2,000	$ 390,000
	Loop Detector Inductive, F&I, Type 11 (2 EA 4 channel card)	EA	64	$	$ 32,000
	Pull Boxes, F&I	EA	195	$ 1,200	$ 234,000
Application Development	Smartphone Application Program Interface (API)	LS	1	$	$ 200,000
	Develop Pedestrian and Truck Weigh Station Modules	LS	1	$	$ 100,000
RSUs	Road Side Units, F&I	EA	65	$ 10,000	$ 650,000
	RSU pole, power, and point-to-point	AS	4	$ 15,000	$ 60,000
OBUs	Deploy On-board Units on Test Vehicles	EA	250	$ 5,000	$1,250,000
	Sub Total				**$5,371,900**
	Design	LS	15%		$ 805,785
	ConOps/PSEMP	LS	1		$ 200,000
	Volunteer of Smartphone Use (2-year)	EA	500	$	$ 100,000
	Test, Train, Integrate, and Configuration Support	HR	400	$	$ 80,000
	Contingency	LS	8%		$ 429,752
	Finalize PSEMP	LS	1		$ 50,000
	Cloud Hosting Service (per year)	PY	65	$ 1,000	$ 65,000
	RFP Development	LS	1		$ 125,300
	Project Management	LS	3%		$ 161,166
	CEI	LS	15%		$ 805,785
	MOT, Mobilization	LS	8%		$ 429,752
	Before and After Study	LS	1		$ 400,000
	Total Project Cost (Future Work)				**$9,024,440**
	Preliminary Engineering (PE)				$ 250,000

	PE (SQL Server, Transparity TMS)				$ 30,826
	Construction (CON) (2070 Controller 1C Module Upgrade)				$ 12,000
	Previously Incurred Cost				**$ 292,826**
	Total Project Cost (Includes Previously Incurred Cost)				**$9,317,266**

Note: ATSPM = Automated Traffic Signal Performance Measures; F&I = Funish and Install; MFES = Managed Field Ethernet Switch; NTCIP – National Transportation Communications for ITS Protocol; OBU – Vehicle On-Board Units; SEMP – Project Systems Engineering Management Plan; RTMC – Regional Traffic Management Centers; SPaT – Signal Phase and Timing

Operation and Maintenance Costs

The operation cost includes the cost of employing two staffs – an engineer and a technician. The base year rate is $75 per hour and the total cost is obtained over the entire year by assuming the office hours in a year to be 2080 hours. The maintenance cost is assumed to be 10% of the CV deployement costs. In addition to the salary of the staff and the maintenance cost, Operations and Maintenance (O&M) cost (shown in Table 2) also includes the cost of 65 cellular services. The annual O&M cost in base year dollars is $914,000 and the total O&M cost for the project discounted by 7% rate is $7.71 million.

Table 2. O&M cost distribution

#	Item	Description	Quantity	Unit Rate	Total Cost
1	O&M Cost	Operations Cost (2 staff – Engineer/Technician)	2080	$75	$ 312,000
		Maintenance Cost	1	10%	$ 537,000
		Cellular Service	65	$1,000	$ 65,000
		Total O&M Cost			**$ 914,000**

Benefits

There are three main derivatives for benefits – safety, mobility, and environmental. The BCA procedures mentioned in the following sub-sections explain about different modes of transportation including freight, transit, emergency vehicles, as well as all the vehicles.

Travel Time Savings

The travel time savings due to the deployment of CV infrastructure is estimated for all modes of transportation – freight, vehicle, transit, and emergency vehicles. For the most part, U.S. 1 has one lane each direction. Therefore, the delay experienced due to various events by all the modes of transportation would be similar. However, delays would be different in a few instances; for example, the freight would have more delays for weight checks along the corridor.

The implementation of the CV project would improve the traffic flow as the users would make a more informed decision using the detections from their onboard unit. This would result in travel time savings. The units for a value of travel time savings (VTTS) would be presented in dollars per person/hour.

Vehicle Travel Time Savings

The delays on the corridor are accounted for due to multiple events. These events (as shown in Table 3) includes the presence of traffic signals, a drawbridge, congestion, left/right turns, school buses, construction, accidents, emergency vehicles, and other special events. Upon the deployment of CV infrastructure, there would be a reduction in delays and thus, savings in travel time for the vehicles on the roadway. Here are the possible scenarios which would lead to the reduction in delays:

- The traffic signals would have roadside units (RSUs) installed that would enable the vehicles equipped with onboard units (OBUs) to respond upstream of the signals. This would allow the vehicles to accelerate or decelerate so that they can clear the intersection. The delay for these vehicles would decrease because of the traffic signals.
- The drawbridge also accounts for the delay of vehicles. Informed decisions by the vehicles would save their travel times.
- Information regarding congestion or accidents would allow the vehicles to avoid queueing and that could help in platoon dispersion.
- The left/right turns and stopping of school buses on a single-lane highway adds to the delay of the vehicles. The CV infrastructure would enable the vehicles to be aware of these events and accelerate/decelerate to avoid queueing.

The savings in delay would be accounted for the travel time savings. The average delay[2] on the corridor was 14 minutes and 11 seconds. Based in the research[3] by the Intelligent Transportation Systems (ITS) Joint Program, "Combinations of signal control applications (Intelligent Traffic Signal System, Freight Signal Priority, Transit Signal Priority, and Freight Signal Priority) reduced travel time by up to 27 percent."

Table 3. Delay time accrued for multiple events along the corridor

Delay Events	Delay Time
Traffic signal	4:30
Drawbridge	0:40
Congestion	7:02
Left Turns	0:10
Right Turns	0:01
School Bus	0:11
Construction	0:00
Accidents	0:06
Emergency Vehicles	0:18
Special Events	1:13
Total	14:11

In this study, it is assumed that the savings due to the deployment of the CV infrastructure would result in a decrease of 30 percent of delay time. Table 3 above shows the delay time accrued on a trip along

[2] https://www.monroecounty-fl.gov/DocumentCenter/View/13496/2017-Arterial-Travel-Time-and-Delay-Study
[3] https://www.its.dot.gov/factsheets/pdf/connectedvehiclebenefits.pdf

the corridor due to multiple events. The average trip length is assumed to be 50 percent. The CV deployment would save 2 minutes and 7 seconds travel time for vehicles based on the calculation below, the occupancy for vehicles are assumed to be 1.68:

Vehicle Travel Time Savings per trip (hour) $= 30\%$ *of* 50% *of* 14:11
$= 2$ *minutes* 7 *seconds*
$= (15/60+4)/60 = 0.035$ *hrs*

Vehicle passenger per day = *vehicle Average Annual Daily Traffic (AADT) (except freight/transit/EV) *average occupancy*
$= 19{,}393 * 1.68 = 32{,}580$

Vehicle Travel Time Savings per day = *Vehicle Travel Time Savings per trip*Vehicle passenger per day*
$= 0.035 * 32{,}580 = 1{,}149$ *hours*

Vehicle Annual Travel Time Savings = *Vehicle Travel Time Savings per day*Annual working days*
$= 1{,}149 * 260 = 298{,}832$ *hours*

Value of Travel Time Savings = *\$16.10 (for all-purpose)*

Vehicle Annual Value of Travel Savings = *Vehicle Annual Travel Time Savings*Value of Travel Time Savings*
$= 298{,}832 * 16.10 = \$\,4{,}811{,}195$

Total Vehicle Annual Value of Travel Time Savings = *Vehicles + Freight + Transit + Emergency Vehicle*
$= \$4{,}811{,}195+\$4{,}171{,}968+\$112{,}801+\$2{,}947$
$= \$9{,}098{,}911$

Based on the calculations above, the total vehicle annual value of travel time savings for the base year is \$9.10 million. Using the AADT growth factor of 1% from 2020-2029 and the discount rate of 7%, the net present value of travel time savings for the project obtained is estimated at \$100.91 million for vehicles.

AADT – Demand Forecast

The 2017 baseline year AADT data is obtained from the Florida Department of Transportation's Florida Traffic Online Web Application. Traffic forecast is estimated both under the baseline and the after-deployment scenario. There is no induced demand on the corridor due to the installation of the CV infrastructure. The growth in AADT is assumed to be similar in both build and no-build scenarios. The annual growth rate is not constant over the entire period of analysis since upon doing so the travel speed would reduce significantly, which would be unrealistic. The travelers or freight carriers would instead opt for possible transfer facilities or a scattered time period if the demand increases that leads to traffic queues and high delays. For ten years, from 2020 to 2029, the growth rate is assumed to be 1%. Based on the previous year's data[4], in about 10 years the traffic saw a growth of 10%. The growth rate after 2029 is assumed to be 1. This is because the assumption is made that if the demand increases capacity, the additional traffic would change their commute patterns.

[4] https://www.monroecounty-fl.gov/DocumentCenter/View/1186/2015-Arterial-Time-and-Delay-Travel-Study

Freight Travel Time Savings

In the base condition in 2017, the freight volume, vehicular volume, and the transit ridership are estimated. Further average growth factor based on past year data is assumed to obtain future trips. The volume of freight is between 7 to 12% out of the total vehicle AADT between 11,000 to 32,000. On average, there are 1,926 trucks that are traveling on the corridor daily. After the deployment of CV, there would be travel time savings for each truck. The travel time savings for each freight trip is obtained during these possible scenarios:

- The deployment of weigh in motion would enable the truck drivers to proceed without making a stop. This would save their travel time by 5 minutes.
- Freight signal priority would give right of way to trucks that would reduce their delays.
- The onboard unit installed in the truck would give advance warning to the drivers regarding any operational decision that they need to make; for example, if there is a crash, the drivers could stop at a rest area upstream, thus causing less congestion.
- The advance warning for the road closure on the draw bridge would help truck drivers to schedule their trimming in such a way that they could avoid queuing upstream.

The travel time savings for the freight would be 7 minutes and 7 seconds or 0.119 hours on the corridor. Using the freight value of travel time savings of $28.60 and truck AADTS of 1,926 along with 260 official days, the net annual travel time savings for the truck is calculated:

*Freight Annual Value of Travel Savings = 1,926 (AADT)*0.119 (TTS in hours)* 260 (days)*28.60 ($ Value of Travel Time; VOTT)*
= $ 1,704,547

Freight Operating Cost Savings

Savings in the operator cost of freight is calculated using the average speed of 46 mph and the value for commercial trucks per mile of $ 0.90:

*Savings in freight operating cost = time savings per year * average speed * operating cost per mile*
*= 59600 * 46 * 0.90*
= $ 2,467,421

Freight Value of Annual Travel Time Savings = Savings in freight operating cost + freight VOTT
= $ 2,467,421 + $ 1,704,547
= $ 4,171,968

Transit Vehicle Travel Time Savings

There are two transit agencies that commute on the U.S. 1 corridor – the Key West Transit[5] and Miami-Dade Transit[6]. On average, the total number of trips made in both directions is 19. The occupancy for the

[5] https://www.kwtransit.com/
[6] https://www.miamidade.gov/transit/mobile/metrobus_route_select.asp?type=BusTracker

transit buses is assumed to be 25 along with the driver. The transit signal priority on any approach would aid the traffic to have the right-of-way in the direction of movement of transit. Since most of U.S. 1 is a one-lane corridor in one direction, this would save the travel time for all the vehicles on that approach. As a result, the savings in travel time for transit are the same as the savings in travel time for vehicles, which is computed as 0.035 hours. The value of travel time (VOTT) for bus riders and bus driver are $16.10 and $30.00 per hour respectively. The transit value of annual travel time savings is calculated to be $112,801.

Emergency Vehicle Travel Time Savings

The deployment of the CV infrastructure would enable the pre-emption of traffic on arrival of emergency vehicles. These emergency vehicles are first responders including police, emergency medical services (EMS), and fire and rescue trucks. The additional saving in travel time upon the arrival of any of these emergency vehicles are assumed as 3 minutes. The annual emergency vehicle trips are estimated using the crash data. It is assumed that 20% (fatal + Injury crashes) of the annual crash would need more than first responders. Therefore, the average daily trips for emergency vehicles would be the total crashes divided by 365 and factored to 1.2 times. The emergency vehicle (EV) value of annual travel time savings is calculated to be $2,947.

Safety Benefit

The crash data for three years from 2015-2017 are obtained from the FDOT's signal 4 analytics[7] webpage. These crash data are classified into different crash types based on their severity – fatal, incapacitated, non-incapacitated, injury, and property damage only. The annual average crashes are obtained from the three-year crash data. The future year crashes would be the same as the average annual crash from historical data in baseline year and the baseline crash risk is 1. Further, these crashes are monetized using USDOT guidelines for a KABCO level monetized value.

To obtain the crash modification factor, there are no crash data for CV, so based on research[8] using the value from simulation, the Crash Modification Factor (CMF) is obtained for different proportions of CV on the facility. A linear regression model is developed to obtain the relationship between the percentage of CV deployed and the CMF. Based on the assumption that in 20 years of deployment, the market penetration for CVs would be 30%, the CMF comes to be 0.947 and the Crash Reduction Factor is rounded to 5 % .

$$\begin{aligned} \text{Safety benefits} &= \sum(\text{annual average crash for each type} * \text{monetized value for respective type}) * CRF \\ &= (17*\$9{,}600{,}000 + 88*\$459{,}100 + 268*\$125{,}000 + 209*\$174{,}000 + 1{,}929*\$4{,}300)*5\% \\ &= \$14{,}081{,}312/\text{year} \end{aligned}$$

[7] https://s4.geoplan.ufl.edu/analytics/

[8] https://www.researchgate.net/publication/329687716_Understanding_the_Safety_Benefits_of_Connected_and_Automated_Vehicles_on_Arterials'_Intersections_and_Segments

According to a research by National Highway Traffic Safety Administration (NHTSA)[9], about 94% of the crashes are attributed to drivers. So the penetration of automated vehicles (AV) would lead to higher reduction in crashes. In the COAST project the deployment of CVs would yield a saving of 5% crashes with 30% penetration. Basic automation like lane departure assist and emergency braking are expected to be incorporated in the vehicles. However, CV penetration is anticipated to grow faster than 30% in next 20 years due to private party on-board unit and cell phone applications development/penetration. Also it is possible that with higher level of automation in future years, the savings in crashes would be more than our assumptions for the COAST project.

For the safety benfits for freight, the deployment of CVs would also prevent crashes due to WIM. The annual average crashes a mile upstream and downstream of WIM was obtained as 3. It is assumed that 50% of the crashes due to WIM would be reduced after the CV deployement.

The savings in safety benefits for future years are discounted to obtain the net present value for the base year of 2017. The total monetized value of safety benefit for vehicles is $295.71 million and the 7% discounted value is $144.38 million. The safety benefits for freight is also obtained in a similar way by using freight crash data. The total monetized value of safety benefit for freight is $32.67 million and the 7% discounted value is $15.95 million.

Environmental Benefits

The emission benefits due to a reduction in emissions of pollutants like CO2, VOCs, NOx, PM2.5, and SO2 are estimated. The number of reduced emissions of each pollutant in the future 20 years is multiplied by the dollar value of avoiding each ton of emissions of that pollutant.

For the example calculation, the project will lower PM2.5 by 1.47 short tons annually; using the recommended monetized value for damage costs of emission, this reduction would result in $556,847 in benefits annually over its lifetime for all the vehicles.

Other emissions should be calculated similarly with their respective monetized value.

$$\begin{aligned} PM_{2.5}\ Reduction\ Benefit &= Quanity\ Reduced\ x\ Monetized\ Value \\ &= 1.47\ short\ tons\ x\ \$377{,}800/short\ ton \\ &= \$556{,}847/year \end{aligned}$$

The economic value of reduced emissions during each year of the project's lifetime is discounted to its present value for use in the overall BCA evaluation. The total environmental cost of the project after the 7% discount rate is $14.74 million for all the vehicles and $5.51 million for freight.

9 https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812506

Disbenefits

The deployment of the CV infrastructure would be carried out in the off-peak hours or during weekends. There would be no right-of-way closure and the traffic would be operational throughout the day. Due to no work zone or lane closure, the disbenefit for this project is assumed to be zero.

Residual Value

Residual value is estimated using the total value of the asset and the remaining service life at the end of the analysis period. The analysis period is 20 years of operation from 2020 to 2039. The service life for the deployed CV infrastructure is 20 years as well. Therefore, the residual value of the project would be zero. There would be no residual value in the numerator during the calculation of the Benefit-Cost (BC) ratio.

Benefit-Cost Ratio

The benefit-cost ratio of this project is calculated taking into consideration all the benefits (mobility, safety, and environmental) along with the operation and maintenance cost and the deployment cost. The disbenefit and the residual costs are zero. To obtain the Benefit-Cost ratio, the O&M cost is subtracted from the Benefit in the numerator and the deployment cost is placed in the denominator:

$$B/C = \frac{Total\ Benefit\ - O\&M\ Cost}{\text{Deployement Cost}}$$

$$\left(\frac{B}{C}\right) 7\%\ Discounted\ NPV = \frac{\$260{,}025{,}700 - \$7{,}711{,}300}{\$9{,}317{,}300}$$

$$\left(\frac{B}{C}\right) 7\%\ Discounted\ NPV = 27.08$$

The Benefit-Cost ratio for 20-year analysis of the project after 7% discount rate is 27.08 for all the vehicles and 6.44 for freight.