Implementing and Testing a Real Time Network Positioning System for Connecticut Department of Transportation: Advanced Continuously Operating Reference Network (ACORN)

FINAL REPORT

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Acknowledgments

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Standard Conversions

Symbol	When You Know	Multiply By	To Find	Symbol
SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
		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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16. Abstract

The Connecticut Department of Transportation (CTDOT) has evolved its Continuously Operating Reference Stations (CORS) from only serving static data to also serving streaming real-time messages that allow roving global navigation satellite system (GNSS) receivers (such as the U.S. NAVSTAR Global Positioning System [GPS]) to determine centimeter-accuracy positions in real time.

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Introduction and Background Summary

The Connecticut Department of Transportation (CTDOT) has evolved its Continuously Operating Reference Stations (CORS) from only serving static data to also serving streaming real-time messages that allow roving global navigation satellite system (GNSS) receivers (such as the U.S. NAVSTAR Global Positioning System [GPS]) to determine centimeter-accuracy positions in real time. This capability is:

- to provide support to CTDOT personnel and contractors using Trimble Site Controller Software (SCS900) and Trimble Siteworks, and,
- to support CTDOT Survey Operations and other positioning-dependent CTDOT engineering activities. As an ancillary benefit, the service is available at no charge to Connecticut residents, including land surveyors and mappers.

CTDOT operates nine Trimble GPS base station receivers, which form the CTDOT CORS. This system is administered and maintained by UCONN for CTDOT and is called the Advanced Continuously Operating Reference Network (ACORN). ACORN is also streaming data from a base station in New York (Riverhead Long Island), two base stations in Massachusetts (Shelburne Falls and Sturbridge), and one base station in Rhode Island (Providence), for a total of thirteen receivers for the entire network.

GNSS data can be used kinematically to allow centimeter-accuracy positioning in real time via a process called real-time kinematic (RTK) positioning. Although RTK positions are generally less accurate than static positions, RTK can achieve accuracies sufficient for topographic land surveys and for quality assurance checking of as-built works. RTK presents a substantial efficiency bonus over other positioning technologies for these purposes.

GNSS real-time positioning requires there be a stationary receiver, called a “base,” be operated at a reference location. The base observes all satellites in view and broadcasts those observables to roving GNSS receivers (called “rovers”) that are conducting fieldwork. With RTK, the base communicates to the rovers either by FM radio or over the Internet via cell phones. When implemented as described, a primary disadvantage of RTK is the necessity of placing the base in the field and supervising it during the day, effectively tying up a person to “baby sit” the station instead of performing more valuable tasks. Another disadvantage is that, for linear surveys, the base might need to be moved throughout the day because positioning accuracy and the base-rover communication link tend to degrade with separation.

The existing CORS can be modified to act as RTK base stations, thus obviating the need for fielding an on-site unit (within accuracy limitations). It is also possible to create a “virtual” base station using a network of permanent base stations, such as the CTDOT

CORS network. A virtual base station is created by sophisticated software that pools the observables from the network together to interpolate the observable that would have been recorded by an actual base station located very close to the rover. Virtual base stations eliminate the need to field an actual, physical base station receiver, and they move automatically and instantaneously along with their rover, which eliminates the need to move an actual base station and mitigates accuracy degradation from base-rover separation. The software and hardware system that implements such real-time positioning is called a real-time network (RTN). For many surveying and mapping tasks, RTN positioning gives a dramatic efficiency improvement over RTK positioning.

CTDOT currently uses Trimble Site Controller Software (construction-site inspection software- SCS900) and Trimble Siteworks (which is replacing SCS900) to conduct quality assurance and quality checking of projects before accepting them as having met specifications. Running on a ruggedized handheld collector that communicates with an RTK/RTN rover, SCS900/Siteworks displays georeferenced design documents (e.g., MicroStation CAD layers for topography, digital terrain models, plans, plats, control markers, etc.) in the field so the inspector, who uses the rover, can use these data to check the project and to document as-built locations of important features.

Problem Statement

This project consists of testing the additional base stations that are being added in Rhode Island. This will consist of construction inspection testing. Summer testing should be contrasted with Fall/Winter testing to document performance in worst/best case conditions. Unlike occupying control points, which exercises “absolute” positioning performance, inspection testing will exercise “localization,” a positioning methodology in which the GNSS receiver constructs a project-specific, local datum by occupying high-accuracy control points for the project.

Other issues entail:

- The base stations that compose ACORN are nearing obsolescence and need to be replaced.
- Develop and recommend a support cost estimate for ongoing operations in a production mode.
- Author final recommendations and report.
- RTK equipment used for testing at UCONN is no longer functioning and needs to be replaced.

Objectives

CTDOT requires real-time network positioning to support the activities of construction inspectors, engineers, and of surveyors. The inspectors will use the RTN in conjunction with SCS900 and Siteworks software (Trimble) to perform post-construction assessment of deliverables from contractors. Survey Operations will use the RTN for positioning activities that do not require geodetic-quality accuracy.

The FY2019-FY2022 objectives were to finish testing and evaluating ACORN in preparation for the transition to a production service and to create a plan for the transition.

Work Summary

The following work tasks have been accomplished:

Partner with Neighboring States.
The system currently operates with nine base stations owned by CTDOT and streams data (to enhance the ACORN network) from four additional base stations: two in Massachusetts, one in New York, and one in Rhode Island (see Figure 1).

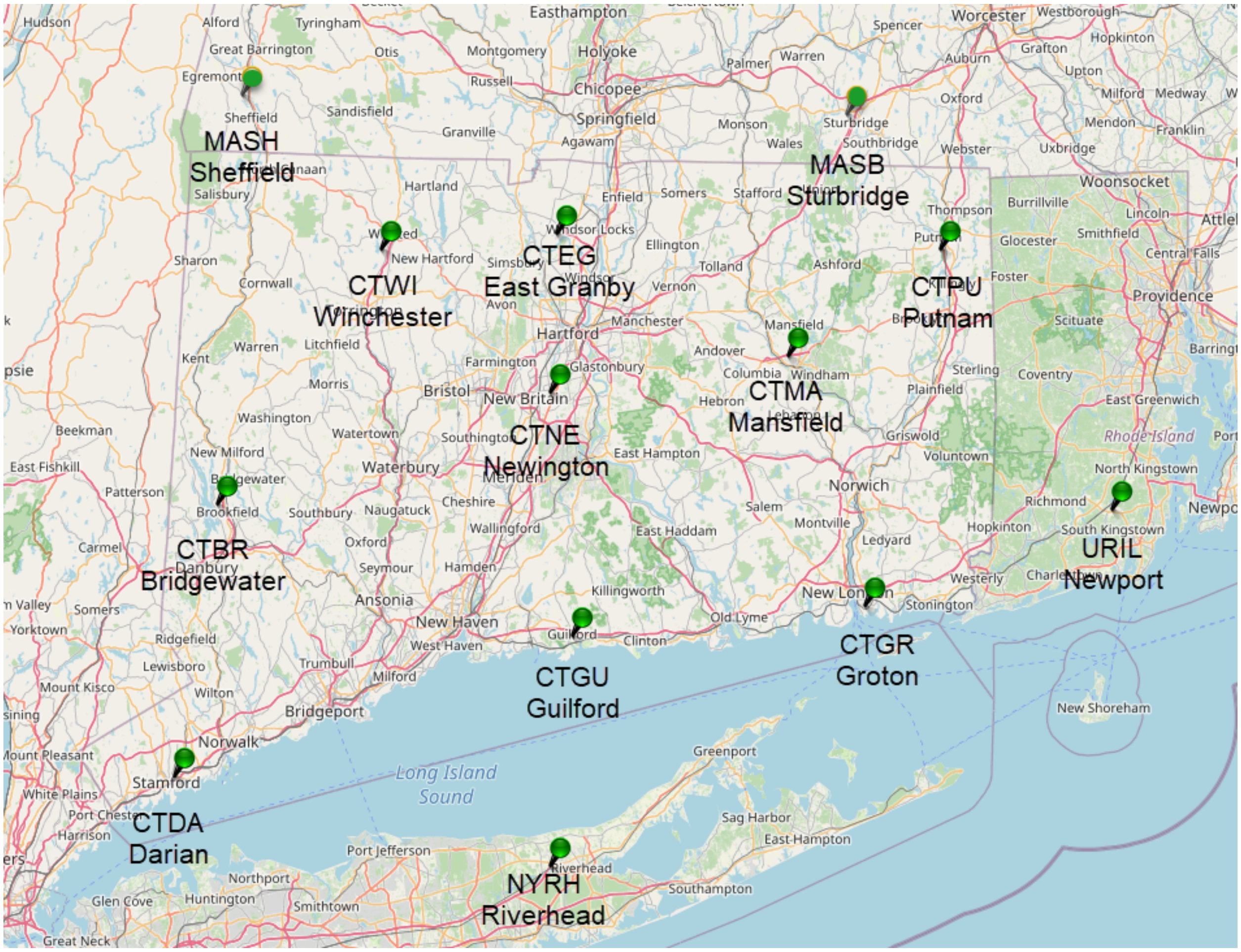

Figure 1: Sensor Map - ACORN

PIVOT software

Replaced and tested the outdated version of the PIVOT ™ software that is used to operate the base stations, completed in the summer of 2021.

Base Stations

Replaced the existing outdated base stations that were nearing obsolescence and ensured that the new base stations functioned within the current network. The nine existing base stations have been replaced with new stations; an additional base station was purchased for backup (see Table 1).

Table 1: Base Station Replacements

Base Station	Location	Date Installed
CTNE	Central Surveys, Newington	12/21/2018
CTMA	Mansfield Maintenance	8/28/2019
CTEG	Granby Repair	9/11/2019
CTGR	Groton/New London Airport	9/25/2019
CTGU	Guilford Maintenance	10/9/2019
CTWI	Winsted Repair	10/30/2019
CTPU	Putnam Repair	11/13/2019
CTDA	Darien Maintenance	1/28/2021
CTBR	Brookfield Maintenance	2/10/2021
Spare	Central Surveys, Newington	

Replace non-functioning RTK equipment.
New equipment was acquired to replace obsolete equipment.

Siteworks Software

Tested the new inspection software, Siteworks™ that is replacing the current software, Site Controller Software 900 (SCS900).

- Installed and tested the new software.
- Updated training manuals/workflows.
- Trained personnel on the use of Siteworks.

Ongoing Operations

Develop and recommend a support cost estimate for ongoing operations in a production mode (see Figure 2).

University of Connecticut Sponsored Program Services						6 mos	12 mos	12 mos	12 mos	12 mos	6 mos	
Digital Design Environment						Year I	Year 2	Year 3	Year 4	Year 5	Year 6	Total
A. **Senior Personnel**		**Salary**	**Appt**	**Months Effort**	**% Effort**	01/01/2022-06/30/2022	07/01/2022-06/30/2023	07/01/2023-06/30/2024	07/01/2024-06/30/2025	07/01/2025-06/30/2026	07/01/2026-12/31/2026	
Thomas Meyer, PI AY				-		-	-	-	-	-	-	-
				-		-	-	-	-	-	-	-
												-
B. **Other Personnel**												-
Post Docs				-								-
Graduate Assistants - AY Level 3 year 1		$16,118	5	5.00	100.00%	16,118						16,118
Graduate Assistants - AY Level 3 Year 2-5		$29,592	9	9.00	100.00%		29,592	30,184	30,788	31,404		121,968
Graduate Assistants - AY Level 3 Year 6		$14,236	4	4.00	100.00%						14,236	14,236
Graduate Assistants - Sum Level 3 year 1		$3,273	1	1.00	100.00%	3,273						3,273
Graduate Assistants - Sum Level 3 year 2-5		$10,015	3	3.00	100.00%		10,015	10,215	10,419	10,627		41,276
Graduate Assistants - Sum Level 3 year 6		$7,227	2	2.00	100.00%						7,227	7,227
Network Operator, Kevin Franklin, SPAR year 1		$7,398	6	6.00	100.00%	7,398						7,398
Network Operator, Kevin Franklin, SPAR year 2-5		$15,536	12	12.00	100.00%		15,536	16,313	17,129	17,985		66,963
Network Operator, Kevin Franklin, SPAR year 6		$9,442	6	6.00	100.00%						9,442	9,442
					Total Salaries	26,789	55,143	56,712	58,336	60,016	30,905	287,901
Enter Fringe Rates												
C. **Fringe Benefits**	**FY22**	**FY23**	**FY24**	**FY 25**	**FY26 & 27**							
Thomas Meyer, PI AY												
Graduate Assistants AY	15.8%	16.3%	16.8%	17.3%	17.3%	2,547	4,823	5,071	5,326	5,433	2,463	25,663
Graduate Assistants SUM	21.9%	22.5%	23.0%	23.5%	23.5%	717	2,253	2,349	2,448	2,497	1,698	11,962
Network Operator, Kevin Franklin, SPAR	21.9%	22.5%	23.0%	23.5%	23.5%	1,620	3,496	3,752	4,025	4,226	2,219	19,338
					Total Fringe Benefits	4,884	10,572	11,172	11,799	12,156	6,380	56,963
					Total Salaries & Fringes	31,673	65,715	67,884	70,135	72,172	37,285	344,864
D. **Equipment**	*											
E. **Travel**	*Domestic*											-
	Foreign											-
F. **Participant Support Costs**	*# of Participants: _____*											-
Stipends												-
Travel												-
Subsistence												-
Other												-
					Total Participant Costs	-	-	-	-	-	-	-
G. **Other Direct Costs**												
Materials & Supplies-Equipment - Maintenance & Replacement Costs						2,500	2,500	2,500	2,500	2,500	2,500	15,000
Publication Costs												-
Pivot system maintenance costs						63,654	31,807	31,807	31,807	31,807	15,904	206,786
Trimble Business Center Software						6,563	1,325	1,325	1,325	1,325	663	12,526
Subawards	**											-
Other - CTDOT SIM Cards						6,000	12,000	12,000	12,000	12,000	6,000	60,000
					Total Other Direct Costs	78,717	47,632	47,632	47,632	47,632	25,067	294,312
H. **Total Direct Costs**	*YR 1*	*YR 2*	*YR 3*	*YR 4*	*YR 5& 6*	110,390	113,347	115,516	117,767	119,804	62,352	639,176
I. **Indirect Costs (F&A) @ 20% per waiver**	***20.0%***	***20.0%***	***20.0%***	***20.0%***	***20.0%***	22,078	22,669	23,103	23,553	23,961	12,470	127,834
Enter Indirect Cost Rates												
J. **Total Costs**						**$132,468**	**$136,016**	**$138,619**	**$ 141,320**	**$143,765**	**$ 74,822**	**$ 767,010**
Indirect Cost Base (TDC)						**$110,390**	**$113,347**	**$115,516**	**$ 117,767**	**$119,804**	**$ 62,352**	**$ 576,824**

Figure 2: Budget for Ongoing Operations

Author final recommendations and report.
This document fulfills that work task.

SIM Cards
Fund the SIM cards used for the mobile GPS data collectors – this need was overlooked in the initial proposal. The funding for the SIM cards is included in the budget for ACORN going forward.

Results/Findings

Background

This report is the final report for an eleven-year effort to upgrade, test and implement a viable CORS network for the State of Connecticut. This project was undertaken in three phases:

- SPR-2353 “Development of the Digital Design Environment ProjectWise™ – Phase 1” (May 2008 – April 2017);
- SPR-2253 “Development of the Digital Design Environment ProjectWise™ – Phase 2” (May 2017 – December 2019); and,
- SPR-2319 “Implementing and Testing a Real Time Network Positioning System for Connecticut Department of Transportation: Advanced Continuously Operating Reference Network (ACORN)” (January 2020 – December 2021).

In June 2010, CTDOT partnered with the Department of Natural Resources and the Environment at the University of Connecticut (UCONN) to upgrade the CTDOT CORS GPS base stations. The upgrade provided real time corrections in support of the Department’s GPS Construction Inspection initiative. The real-time network is known as Advanced Continuously Operating Reference Network (ACORN) and is hosted at UCONN. This service is free of charge to the public or any government agency.

This GPS initiative utilizes Electronic Engineering Data (EED), provided by the Bureau of Engineering and Construction, to perform construction inspection and other activities. The EED is made available on the State’s contracting portal (along with the contract plans, specifications, and estimates) to the contractors and inspectors at advertisement for all applicable projects.

EED is produced during the design phase and includes two-dimensional (2D) CAD models, three-dimensional (3D) terrain models, coordinate geometry files and drainage data. This data is useful for GPS functions, including:

- Quantity estimation,
- Automated stakeout,
- Construction equipment automated control/guidance (AMC/AMG),
- Uniform compaction,
- Generation of “live” as-built drawings,
- Inspection and verification, such as use of GPS to measure for payment,
- Asset management; and,
- GIS.

Without the EED, contractors have been generating digital data by repurposing the contract portable document format (pdf) plans provided by the Department. This process is time consuming, costly, and potentially unreliable. Providing design generated EED to ‘downstream’ users (i.e., inspectors, bidders, contractors) will improve the efficiency, accuracy and quality of the bidding, inspection and construction processes. The construction inspection activities include using the hand-held GPS equipment as an approved method of measurement for pay items, verification of layout, and the automated production of as-built drawings. Typically, all these functions utilize the same set of data points, which are easily collected in the field using a rover versus using the more cumbersome “wheel and tape” method. This results in a tremendous reduction of time spent collecting and processing field measurements.

This system is also currently being used to accurately collect CTDOT asset data. Likewise, it can be used by the contractors for automated machine control/guidance of heavy construction equipment.

After use on approximately 200 projects over the last eleven years, the use of EED along with the ACORN CORS network has proven to be very successful for the Construction Inspection initiative.

Additional hardware, hosting and consulting services were procured to study the use of corrected GPS technologies used in advanced construction inspection techniques. The task studied the repurposing of engineering byproduct data (EED).

Other state agencies such as the Connecticut State Police, Department of Energy and Environmental Protection, various state universities and several municipalities have utilized the services offered by ACORN. Numerous contractors working on state transportation/capital improvement projects have also used ACORN to facilitate the design/construction of these projects.

The overall outcome of this endeavor has proven to be very successful in bringing the State of Connecticut’s CORS network up to a level of operation that is aligned with current technologies needed to sustain Connecticut in the years to come.

ACORN usage has been growing steadily since it was released to the public in 2013. It now has 198 registered users and continues to add new users every month (see Figure 3).

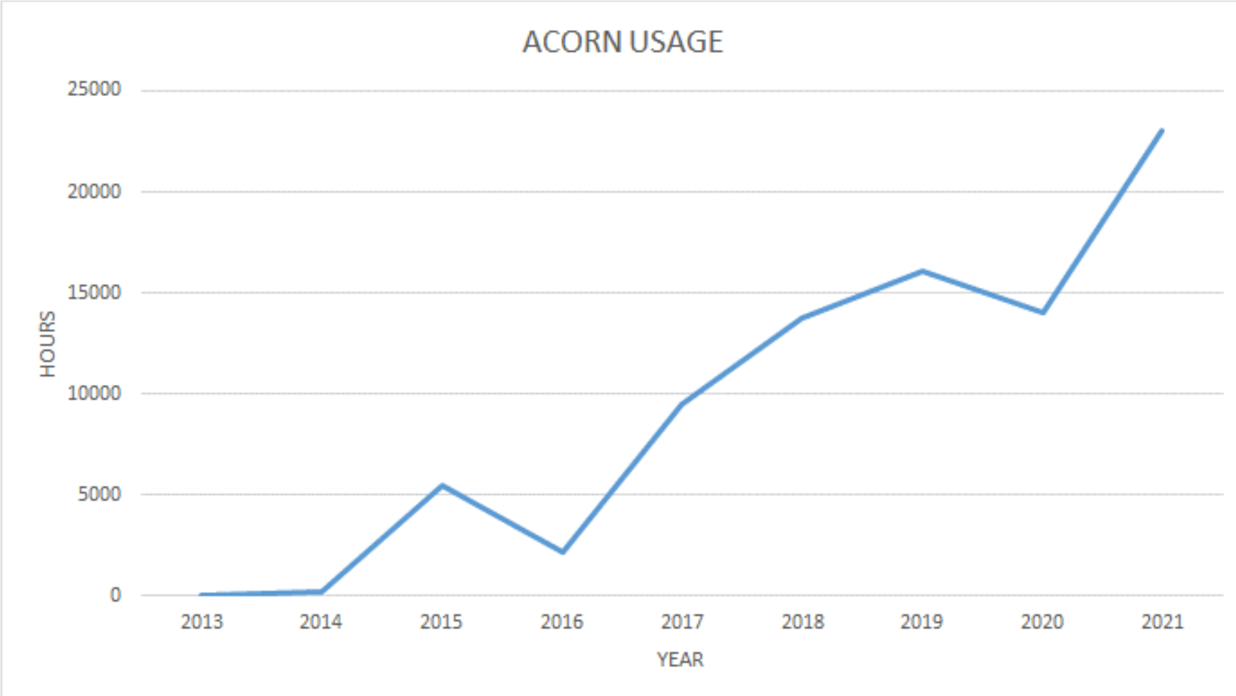

Figure 3: ACORN Usage

ACORN Moving Forward

This project is now in the operational phase. In February 2022, a Memorandum of Understanding was signed between CTDOT and UCONN to continue the operation of ACORN until 2027.

References

[Electronic Engineering Data Delivery, Phase 1 (ECD-2017-4)]