

Assessment of the Trimble MX7 for Use in Creation of Alignment Files for the Intelligent Compaction and Paver Mounted Thermal Profile Methods

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LIST OF ABBREVIATIONS

GNSS	Global Navigation Satellite System
IC	Intelligent Compaction
ICT	Intelligent Construction Technology
PMTP	Paver Mounted Thermal Profile
TBC	Trimble Business Center

EXECUTIVE SUMMARY

As part of the Minnesota Department of Transportation's (MnDOT's) goals to enhance financial effectiveness, a roadmap was established for the deployment of intelligent compaction (IC) and paver mounted thermal profiling (PMTP) technologies. It is well known that the majority of pavement performance issues are related to poor workmanship; and therefore, these technologies are being used to real-time identify these issues and help MnDOT obtain longer-performing roads and reduced maintenance costs.

Starting in the 2018 construction season, MnDOT has moved forward with full deployment on these technologies. However, the effective use of these technologies requires the use of alignment files to be loaded both on the intelligent construction technology (ICT) data acquisition systems and within Veta. These design and alignment files are available for new construction and/or reclamation projects. However, the standard mill and overlay projects typically do not have in-place line work available for use. Consequently, in order to realize the above goals, MnDOT was in need of determining a more financially effective means to create in-place alignment files for use with these technologies on asphalt mill and overlay projects. Current, traditional methods impose safety concerns on surveyors and inspectors when capturing the in-place centerline joint and result in increased time and resources that are not typically needed for these types of projects.

The objective of the work described herein was to purchase and validate a Vehicle-Mounted Mobile Imaging Photogrammetric system to collect infrastructure information for creation of in-place alignment files for use with intelligent compaction (IC) and paver mounted thermal profile (PMTP) technologies and to also provide the capability to collect other asset information along the roadway, while realizing the following benefits:

- Reduction in data collection times compared to the conventional process of creating digital terrain models (DTM) through numerous coordinate shots by survey crews
- Reduction in design efforts
- Time and resource savings
- A safe solution for creation of an in-place (as-built) alignment for records, planning purposes and for utilization with ICTs
- Mobile images that are available for future evaluations to assist with scoping, maintenance, etc.
- An imaging system that could also be used by other specialty units (e.g., Foundations, Research, Pavement Preservation, Asset Management, etc.) for infrastructure monitoring, crack detection, slope monitoring, and asset collection with reduced field time
- The horizontal and vertical accuracy of this system allows for the ability to reference collected data at a later date without having to revisit the site

The Trimble MX7 was chosen as the survey tool for evaluation as it is a Vehicle-Mounted Mobile Imaging Photogrammetric system that collects infrastructure information at the needed accuracy. Also, this system captures 360-degree, 30 megapixel geo-referenced images at highway speeds and deploys on all

sizes of off- and on-road vehicles. The flexibility of this system allows for ease in use for numerous applications.

The system was purchased through this contract, along with receiving the required software and equipment training. Training was provided on the following software platforms: POSPac, Trimble Business Center and Trimble MX Asset Modeler.

Three projects requiring the IC and PMTP technologies were selected from each district for mobile imaging using the Trimble MX7. One of the three projects was used for verification of the Trimble MX7 technology, where conventional survey methods were already used to capture the in-place centerline alignment (projects from construction season 2017). The remaining two projects, from each district, were proactively collected for future use in creation of alignment files for the upcoming construction season (construction season 2018).

Mobile imaging was also collected on SP5510-83 TH63, as this project contained photo targets that were recently placed on the roadway for use in an upcoming LiDAR scan. This allowed for more accurate verification of the system with highly accurate known points on the roadway.

The mobile images were collected at highway speeds on each route by driving one lane per route. The capture rate was set at a 4-meter interval, thereby, allowing 360-degree panoramic images to be captured at this interval along the roadway. These images were able to capture the centerline cold joint, centerline skip lines, fog lines and other roadway assets (e.g., shoulder, guard rails, signs, bridge clearances, etc.). The information was processed through POSPac, Trimble Business Center and Trimble MX Asset Modeler. The resulting processed data file sizes was a concern for future storage of this information as part of asset management. Processed data file sizes were approximately 3.5 GB per centerline mile. Storing the original raw data files will require an even greater amount of storage space.

The mobile images were first processed through POSPac. Using this software, it was noted that on average, the position error of the Trimble MX7 trajectory in the X, Y, and Z direction was found to be 2, 2 and 3 cm, respectively. This small horizontal trajectory error will assist with minimizing the resulting position error of the extracted features obtained through the subsequent steps in the Trimble MX Asset Modeler software.

After processing the data through POSPac, the panoramic images were processed in Trimble Business Center using the resulting corrected trajectory information exported from POSPac. Processing through Trimble Business Center allowed creation of a Trajectory and Panorama *.csv file. These files were then imported into the Trimble MX Asset Modeler software for extraction of the desired features. The centerline features were extracted using the forward intersection and reference plane method. The forward intersection method used two (2) images to assist with extraction of the given feature, while the reference plane only used one (1) image. The reference plane method was quicker at identification of features; however, it was uncertain as to whether the use of only one image would significantly impact the horizontal accuracy of the extracted feature, and therefore, both extraction methods were assessed. It was determined that extraction of the features using the forward intersection method was significantly more accurate (i.e., has less horizontal position error) than that found using the reference

plane method. On average, the differences between the MX7 and photo targets using the forward intersection and reference plane extraction methods were 0.26 ft (3.1 inches) and 1.1 ft (13.8 inches), respectively. While the 95 percent confidence interval for the forward intersection and reference plane extraction methods were determined to be: 0.2 ft (2.9 inches) to 0.3 ft (3.2 inches) and 1.0 ft (12.5 inches) to 1.3 ft (15.0 inches), respectively. Similar position error results to that found with the photo targets were also found when comparing the MX7 positions to alignment files created using conventional survey methods. It was also noted that satellite configurations (time of day) and data collection speed did not appear to significantly affect the results.

Enhancements were made to the Trimble Business Center software since the purchase of the Trimble MX7 system. These enhancements allowed the feature extractions to be conducted within Trimble Business Center in lieu of the Trimble MX Asset Modeler software, thereby, eliminating the need to purchase a licensed copy of Trimble Asset Modeler and to learn how to run this software. Known point comparisons were conducted utilizing a subset (44 percent) of the photo target locations on the TH63 project. The average position error using the forward intersection method from Trimble Business Center and the Trimble MX Asset Modeler software was found to be 0.20 ft (2.4 inches) and 0.26 ft (3.1 inches), respectively. While the 95 percent confidence interval using the forward intersection method using Trimble Business Center and Trimble MX Asset Modeler software was determined to be 0.18 ft (2.1 inches) to 0.22 ft (2.7 inches) and 0.2 ft (2.9 inches) to 0.3 ft (3.2 inches), respectively. As previously noted, 44 percent of the photo targets were assessed for verification of the extractions through Trimble Business Center due to time constraints. This smaller sample population could potentially affect the slight variation in position errors between the two software platforms. Regardless, position error accuracy was well within the desired limits for creation of alignment files for the IC and PMTP methods using the new enhancements in Trimble Business Center. Consequently, it is recommended that this software is used in the future in lieu of the Trimble MX Asset Modeler software to decrease the number of software platforms required for feature extractions.

The following summarizes recommendations resulting from verification of the accuracy of the Trimble MX7 system:

- The Trimble MX7 can be used to capture the in-place centerline for use in creation of alignment files for the IC and PMTP methods.
- The forward intersection method should be used for extraction of features (i.e., in-place centerlines) in lieu of the reference plane method.
- Trimble Business Center can be used to extract features in lieu of the Trimble MX Asset Modeler software.
- Long-term storage options should be considered for storage of the mobile imaging files.
- Districts can use the Trimble MX7 to capture other needed assets, in addition to the in-place centerlines (e.g., locations of mailboxes, guardrails, signs, catch basins, etc.; bridge clearance heights, linear lengths of given assets, etc.).

Additionally, since the time of this assessment there has been increased interest in the use of the Trimble MX7, as districts have been receiving education on the capabilities of this system. The system

has been used in three (3) districts to date for additional mobile imaging beyond that completed in this assessment project.

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

1.1.1 Problem Statement

As part of the Minnesota Department of Transportation's (MnDOT's) goals to enhance financial effectiveness, a roadmap was established for the deployment of intelligent compaction (IC) and paver mounted thermal profiling (PMTP) technologies (see section 1.1.3 for a brief description of these technologies). It is well known that the majority of pavement performance issues are related to poor workmanship, and therefore, these technologies are being used to real-time identify these issues and to help MnDOT obtain longer-performing roads and reduced maintenance costs. The increased financial effectiveness resulting from the use of intelligent construction technologies assists MnDOT with meeting the mission to provide a safe, accessible, efficient and reliable multimodal transportation system. Additionally, the core value of "accountability" is also being met by ensuring that the contractors are following recommended construction practices and that MnDOT is accepting quality work.

Starting in the 2018 construction season, MnDOT has moved forward with full deployment on these technologies. However, the effective use of these technologies requires the use of alignment files to be loaded both on the intelligent construction technology (ICT) data acquisition systems and within Veta. These design and alignment files are available for new construction and/or reclamation projects. However, the standard mill and overlay projects typically do not have in-place line work available for use. Consequently, in order to realize the above goals, MnDOT needs to determine a more financially effective means to create in-place alignment files for use with these technologies on asphalt mill and overlay projects. Current, traditional methods impose safety concerns on surveyors and inspectors when capturing the in-place centerline joint and result in increased time and resources that are not typically needed for these types of projects.

1.1.2 IC and PMTP Project Selection Criteria

The following outlines the project selection criteria that MnDOT uses for inclusion of IC and PMTP on a project. Again, use of these technologies would then require the availability of a design and alignment file that could be loaded onto the data acquisition system and imported into Veta. MnDOT requires the use of IC and PMTP technologies on all projects that are greater than or equal to four (4) net lane miles for the specifications listed in Table 1.1. Additionally, there must be data cellular coverage available at least one time per day and 100 percent global navigation satellite system (GNSS) coverage within the project limits for the given project to require use of these technologies. Chapter eight (8), of the MnDOT Pavement Design Manual, outlines these project selection requirements. This manual can be found at: <http://www.dot.state.mn.us/materials/pvmtdesign/manual.html>.

MnDOT has required the IC and PMTP technologies on approximately 230 projects to date. There are approximately 50-70 asphalt mill and overlay projects that will be using these technologies each year

and each project will require the need for creation of in-place alignments. Consequently, there is a great need to determine a safer, cheaper method for capturing the in-place centerlines, in lieu of using conventional survey methods.

Table 1.1 MnDOT Specifications Requiring the IC and PMTP Methods

Technology	Specification
Intelligent Compaction (IC) Method	2215 (Stabilized Full Depth Reclamation) 2390 (Cold In-Place Recycling Bituminous) 2390 (Cold Central Plant Recycling Bituminous) 2353 (Ultrathin Bonded Wearing Course) 2360 (Plant Mixed Asphalt Pavement) 2365 (Stone Matrix Asphalt)
Paver Mounter Thermal Profile (PMTM) Method	2360 (Plant Mixed Asphalt Pavement) 2365 (Stone Matrix Asphalt)

1.1.3 Description of IC and PMTP Technology

The IC and PMTP technologies are intelligent construction technologies that provide real-time measurements at 100 percent coverage. The PMTP method is a process that continuously monitors and records the location and temperature of the asphalt mat immediately behind the trailing edge of the paver screed during placement operations. These measurements are used to identify the presence of thermal segregation in the uncompacted asphalt, which can affect the pavement's performance and durability. The PMTP system contains a temperature measurement sensor, GNSS receiver, modem and an on-board data acquisition system for real-time viewing and recording of the surface temperature measurements and also provides statistical summary menu(s). The IC method monitors the compaction of road materials, such as soil, aggregate base, or asphalt, using self-propelled rollers integrated with a position monitoring system and an onboard documentation system that can display real-time, color-coded maps of roller location, number of passes, roller speeds, amplitudes and vibration frequencies of the roller drum. Some systems are also equipped with drum vibration instrumentation, temperature sensors, and/or automatic feedback control. The onboard documentation system on these rollers also displays real-time, color-coded maps of stiffness response or pavement surface temperatures, or both. This improves monitoring and recording of the compaction process to ensure that the material is properly and uniformly compacted.

MnDOT requires that the IC and PMTP technologies both store the data internally at least every 5 minutes and transfer the data directly from the device to the cloud storage within 15-minute intervals, or at least once per day when there is limited cellular coverage. This data must then be provided to the Engineer in one of the following formats: (1) as a dbase ASCII or text format; (2) directly into Veta if a file format compatible with Veta is available; or (3) through a direct transfer of data from the cloud storage to Veta. The direct transfer of data from cloud storage to Veta is the preferred import method as this process reduces the number of steps required to export data from the cloud storage and/or cloud mapping software, reduces files sizes and helps ensure data integrity. The design or alignment files are loaded into the on-board display of each IC roller to allow the roller operator to visually see the line-

work of the production area(s) with respect to compaction efforts. This real-time view helps ensure that adequate and uniform compaction efforts occur across the production area and also assists with night-time paving operations. In particular, the alignment file(s) help the roller operators ensure that adequate compaction occurs along the longitudinal joints of the pavement as these locations are often missed during compaction efforts.

1.1.4 Intelligent Construction Data Management Tool (Veta)

Veta is a standardized intelligent construction data management tool that stores, maps and analyzes geospatial data resulting from ICTs (such as IC and PMTP) and can overlay spot test data (e.g., density, moisture) on these data sets. This tool can perform standardized data processing, analysis and reporting to provide project summary results quickly in the field. In particular, it can provide statistics, histograms, correlations for these measurements, document coverage area and evaluate the uniformity of compaction and surface temperature measurements as part of the project quality control operations. Veta can be downloaded from the Advanced Materials and Technology Website at: <http://www.dot.state.mn.us/materials/amt/veta.html>.

The design and alignment files are imported into Veta to allow for more detailed analyses of IC and PMTP data with respect to given locations within the project limits and to allow for removal of miscellaneous data that is not associated with the given compaction/paving efforts. These files also allow users to quickly identify locations of poor workmanship with respect to stationing and/or the edge of pavement.

1.2 DEPLOYMENT OBJECTIVE

The objective of the work described herein was to purchase and validate a vehicle-mounted mobile imaging photogrammetric system (the Trimble MX7) to collect infrastructure information for creation of in-place alignment files for use with the IC and PMTP technologies and also to provide the capability to collect other asset information along the roadway.

1.3 DEPLOYMENT BENEFITS

The deployment benefits for the use of this imaging system are to further meet MnDOT's mission to "plan, build, operate and maintain a safe, accessible, efficient and reliable multimodal transportation system that connects people to destinations and markets throughout the state, regionally and around the world." This system will enhance MnDOT's financial effectiveness and support MnDOT's core values of accountability, safety and service.

The mobile imaging system will reduce collection times compared to the conventional process of creating digital terrain models (DTM) through numerous coordinate shots by survey crews and reduce design efforts, thus saving time and resources. Additionally, it will provide a safe solution for creation of an in-place alignment (as-built) for records/planning purposes and for utilization with ICTs. Data collected can also be used to reduce future construction and maintenance costs.

This imaging system can also be used by other specialty units (e.g., Foundations, Research, Pavement Preservation, Asset Management, etc.) for infrastructure monitoring, crack detection, slope monitoring, and asset collection with reduced field time. The horizontal and vertical accuracy of this system allows for the ability to reference collected data at a later date without having to revisit the site.

CHAPTER 2: EVALUATION PROGRAM

2.1 GENERAL DESCRIPTION

The Trimble MX7 is a vehicle-mounted mobile imaging photogrammetric system that collects infrastructure information. This system captures 360-degree, 30 megapixel geo-referenced images at highway speeds and deploys on all sizes of off- and on-road vehicles.

The Trimble MX7 system was purchased and received on May 23, 2017. Included with the purchase of equipment was specialized training for data collection, software and asset extractions. The Trimble MX7 equipment training and setup was received on May 31, 2017, while the software training was received over a three-day period from July 7 through July 9, 2017. The following subsections briefly summarize the purchased equipment and the software and field training.

2.1.1 Trimble MX7 System Purchasing

The following items were purchased as part of the Trimble MX7 mobile imaging system from Frontier Precision in Maple Grove, Minnesota. See Figure 2.1 for photos of select Trimble MX7 components.

- Item T000925 | Trimble MX7 HW 2.0 - 360DEG, Mobile Imaging System which included the following:
 - Sensor Head,
 - Transportation Case,
 - Quick Release Mounting Plate,
 - Power & Interface Box,
 - Wireless USB Adapter (WLAN),
 - Power-IN Cable with cigarette jack,
 - System PWR Cable 3.5m,
 - System Data Cable 3.5m,
 - Mounting Tools and
 - Getting Started Manual
- Item T000961 | Roof Rack Mount
- Item T000969 | POSpac MMS V7.X Single User License: GNSS-Inertial with Smart Base Tool Set (Node-Locked)
- Item 30310-10 | Trimble MX Asset Modeler Standard
- Item T001014 | Samsung Portable SSD T1 1T with USB3 for Trimble MX7 Data Storage and Transfer
- Item FPIUsed-Controller | Field Controller for operation and processing Trimble MX7 data. Device will meet or exceed specifications of Trimble MX software requirements
- Item FPI-Training-Survey | 1 day training Fee – Trimble MX7 & Trimble MX Software



(a) Photo of Trimble MX7 Unit.



(b) MX7 unit with GNSS receiver.



(c) Power Conversion Unit – 3 ports for 12V in 24V Out data.



(d) Wi-Fi connection to Web UI on the Power Conversion Unit.



(e) 1TB SSD Portable Hard Drive.



(f) Mounting bracket on truck.



(g) Overall view of system mounted on truck.

Figure 2.1 Photos (a) through (g) of Trimble MX7 components.

2.1.2 Trimble MX7 Equipment Training and Setup

Frontier Precision assisted with setup and training of the equipment. The equipment setup required minimal effort and all of the components were present. The system broadcasts a Wi-Fi signal for a web UI interface connection. See Appendices A and B for details on setup of the system and the procedure for collection of the mobile imaging, respectively.

The Trimble MX7 field training was conducted at the MnROAD test facility, where measurements were collected on the Low Volume Road. After collection of the mobile images, the data was downloaded from the data acquisition system to the external hard-drive, which took approximately 10 minutes and an additional eight (8) minutes to copy the data from the external drive to the laptop containing the required software packages. The raw data was then post processed using the POSPac software. Larger data collection efforts will require significantly more time for transferring of data, as this was a small test collection.

Initial training included detailed instruction on the use of the POSPac software and instruction on how to process the collected data set from MnROAD. The Trimble MX Asset Modeler software was then installed on the laptop for use in further processing the data. This training was provided at a later date by the product developer.

2.1.3 Software Training

In-depth software training was provided by a Trimble Certified Training on July 7 through July 9, 2017 at the Frontier Precision office in Maple Grove. This three-day training went through the following elements:

- Description of the system components;
- Calibration certification;
- Details on how the Trimble MX7 system works; and
- Training on the following three (3) software programs that are used to process the data and extract features:
 - POSPac. The POSPac software processes the raw satellite data from 1second-1hour GNO base files to create a Smoothed Best Estimation of Trajectory (*.sbt) file for use in processing the panoramas. The GNO base files are the RINEX files that contain the base station data used to post process the Trimble MX7 trajectory.
 - Trimble Business Center. The Trimble Business Center software is used to process the panoramas and create panorama and trajectory georeferenced images.
 - Trimble MX Asset Modeler. The Trimble MX Asset Modeler software is used to extract features to vector datasets.

The training was recorded during the software workflows to allow for future reference.

2.2 PROJECT SELECTION

Three (3) projects requiring the IC and PMTP technologies were selected from each district for mobile imaging using the Trimble MX7. One (1) of the three (3) projects was used for verification of the Trimble MX7 technology, where conventional survey methods were already used to capture the centerline alignment (projects from construction season 2017). The remaining two (2) projects, from each district, were proactively collected for future use in creation of alignment files for the upcoming construction season (construction season 2018). Table 2.1 lists the projects where the Trimble MX7 was used to collect mobile images.

Table 2.1 Listing of Projects with Trimble MX7 Mobile Images.

District	Construction Year	State Project Number	Route	RP	Location Limits
1	2017	0902-12	TH27	231+00.365 to 240+00.765	Aitkin/Carlton Co Line to W JCT TH73
1	2018	6917-143	TH53	NB41+00 to 47+84 SB 48+00 to 54+00.56	NB end pale face river to .35 mi S CSAH93
1	2018	6928-28	TH73	18+00 to 69+00	Cromwell to Hibbing
1	2018	0110-32	TH65	96+01 to 105+01	0.14 mi S CSAH2 to N jct TH27
2	2017	2906-18	TH 71	280+00 to 287+01	0.3 Mi S of TH200 to 567' W of CSAH4
2	2018	3109-41	TH 46	000+00 to 10+01	US 2 to Itasca CSAH39
2	2018	6011-29	TH 75	321+01 to 334+01	Crookston to Euclid US 2 to Polk CSAH19
3	2017	3003-47	TH 65	30+01 to 41+01	From 245th Ave. to 357th Ave., Isanti County

District	Construction Year	State Project Number	Route	RP	Location Limits
3	2018	8601-64	TH 12	...	East of Cokato to West of Howard Lake
3	2018	8603-09	TH 25	39+01 to 47+01	Watertown to Montrose
4	2017	1402-19	TH32	...	TH34 to TH10
4	2018	2607-11	TH54	...	TH27 to TH55
4	2018	5619-11	TH78	...	500' south of 94 to 210
4	N/A	...	TH55*	48 to 53	SFDR test sections
M	N/A	...	TH 169**	...	Belle Plain to TH 19 Henderson
M	2018	1921-94	TH 3	38+01 to 40+01	TH149 to TH55
M	2018	2706-237	TH 7	188+01 to 192+01	I494 to Louisiana Avenue
6	2017	6607-49	TH60	149+01 to 160+01	Fairbault to Kenyon
6	2018	5507-69	TH52	46.285 to 51.881	NB & SB 0.2 Mi. S. I-90 to T.H. 63
6	2018	7908-35	TH63	59.914 to 68.639	T.H. 60 to CSAH 78
6	2018	5510-83	TH 63**	...	TH14 to Zumbro Falls
7	2017	4008-28	TH 99	13.57 to 26.04	St. Peter & Le Center
7	2018	2208-113	TH 169	12+01 to 20+01	1 Mile N. of TH90 to 0.2 mile north of CSAH 12 in Winnebago
7	2018	8101-57	TH 13	18 to 30	New Richland and Waseca
8	2017	4713-14	TH 55	119+01 to 127+01	Eden Valley (TH22) to Meeker/Stearns County Line
8	2018 / 2019	4101-29	TH 75	...	Ivanhoe to Canby
8	2018 / 2019	8712-32	TH 212	36+01 to 48+00	Montevideo to Granite Falls
* Project contained test sections with varying pavement designs.					
** Project contains photo targets.					

Mobile imaging was also collected on SP5510-83 TH63, as this project contained photo targets that were recently placed onto the roadway for use in an upcoming LiDAR scan. This allowed for more accurate verification of the system with highly accurate known points on the roadway. Please note that photo targets were also available on TH169 (between Belle Plain and TH19 Henderson), however, there were issues with the survey measurements associated with each photo target preventing these from being used in future analyses.

Mobile imaging measurements were also collected on TH53, as this roadway was constructed with various stabilized full depth reclamation designs. Consequently, the district desired a scan of the current roadway condition.

2.3 DATA COLLECTION PERIOD

The mobile imaging on the routes listed in Table 2.1 were collected during the summer months of the 2017 construction season. The resulting data was then mined, with the assistance of Braun Intertec, during the winter months of 2017 and 2018.

2.4 DATA COLLECTION

The mobile images were collected at highway speeds on each route by driving one lane per route. The capture rate was set at a 4-meter interval, thereby, allowing 360-degree panoramic images to be captured at this interval along the roadway. These images were able to capture the centerline cold joint, centerline skip lines, fog lines and other roadway assets (e.g., shoulder, guard rails, signs, bridge clearances, etc.).

Additional data collections were captured at varying times of the day and speeds on TH53 (the roadway containing photo targets) to determine whether time of the day or data collection speed affects the geospatial accuracy of the resulting measurements.

CHAPTER 3: DATA EVALUATION

3.1 FEATURE EXTRACTIONS

After completion of the mobile imaging, the resulting data was backed-up and loaded onto a computer for extraction of features. Users should be prepared to store large volumes of data. The raw data collected for the projects listed in Table 2.1 resulted in 1.75 TB of storage space, while the post processed data files were approximately 3.5 GB per centerline mile. The long-term storage option(s) of these types of assets will need to be addressed in the future as increasingly more projects are mobile imaged each year.

In order to extract the needed features, the data was run through three (3) different software platforms. Figure 3.1 illustrates the flow of the software used for data manipulation.



Figure 3.1 Flow chart of data evaluation software.

3.1.1 POSPAC Software

As illustrated above in Figure 3.1, the data was first analyzed through the POSPac software. This software processed the raw satellite data from 1second-1hour GNO base files to create a Smoothed Best Estimation of Trajectory (*.sbet) file for use in later processing the panoramic images. During this processing, the user is able to see the resulting position error of the system during the actual data collection (i.e., real-time vehicle frame) versus the post processed data after coordinate corrections to create the Smoothed Best Estimation of Trajectory (i.e., post processed SBET). See Appendix C for details on how process the data through POSPac.

Figure 3.2 illustrates an example of the horizontal and vertical accuracy of the Trimble MX7 trajectory as determined through POSPac. The vertical axis of this graph illustrates the position error in units of meters, while the horizontal axis plots time in units of seconds. **On average, the position error of the trajectory in the X, Y and Z direction was determined to be 2, 2 and 3 cm, respectively.**



Figure 3.2 Horizontal and vertical accuracy of the Trimble MX7 trajectory.

Figure 3.3 visually illustrates the horizontal position error of the real-time and post process trajectory in plan-view within POSPac. The POSPac user can pan through the map to visually review the horizontal accuracy at various locations along the project limits. This small horizontal trajectory error will assist with minimizing the resulting position error of the extracted features obtained through the subsequent steps in the Trimble MX Asset Modeler software.

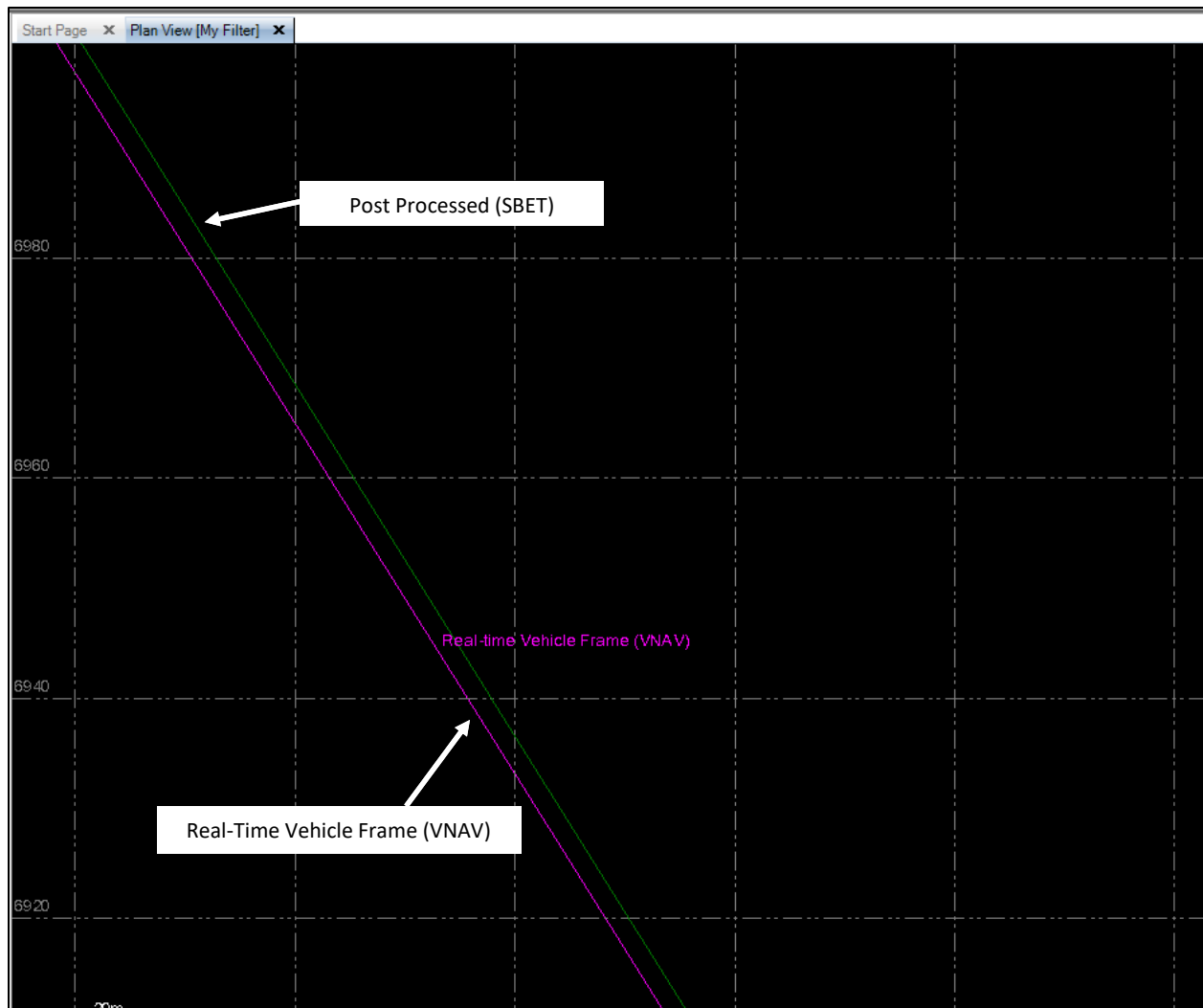


Figure 3.3 Plan view of the horizontal and vertical accuracy of the Trimble MX7 trajectory in POSpac.

3.1.2 Trimble Business Center

After processing the data through POSpac, the 360-degree panoramic images were processed in Trimble Business Center with the resulting corrected trajectory information (SBET) exported from POSpac. Processing through Trimble Business Center allowed creation of a Trajectory and Panorama *.csv file through use of the Trimble MX Panorama Exporter. Again, the objective of this process is to georeference the panoramic images. See Appendix D for details on creating the Trajectory and Panorama files.

3.1.3 Trimble MX Asset Modeler (Forward Intersection and Reference Plane Extractions)

After creation of the Trajectory and Panorama *.csv files, these file were imported into the Trimble MX Asset Modeler for extraction of the desired features. For this project, the centerline was the extracted

feature. See Appendix E for additional details related to the use of the Trimble MX Asset Modeler software.

Figure 3.4 illustrates the panoramic view within Trimble MX Asset Modeler. As illustrated, the top viewing pane provides a plan view of the location of each panoramic image, where the mobile image location is depicted by the blue circles. The bottom pane provides the visual of the 360-degree panoramic photo image. The user is able to pan this image to see the full 360-degrees, as needed.



Figure 3.4 Image of panoramic view within Trimble MX Asset Modeler.

The user is then able to use these dialogue boxes to extract the desired features using either the reference plane or forward intersection method. The forward intersection method uses two (2) images to assist with extraction of the given feature, while the reference plane only uses one (1) image. The reference plane method is quicker at identification of features, however, it was uncertain as to whether the use of only one (1) image would significantly impact the horizontal accuracy of the extracted feature, and therefore, both extraction methods were assessed. Figure 3.5 illustrates the extraction of the centerline using the **reference plane method**. The user selects “line” for the measurement type, clicks on the desired feature (e.g., the centerline joint) and then clicks on the next panoramic image (i.e., next blue circle) to allow progression of the screen to this next image. The user would then click on the desired feature (centerline joint) again and select the next panoramic image to allow progression of the images. This process is repeated until the entire feature has been selected. The user then selects “Copy to Feature” to save the lines for extraction into Trimble Business Center. The fine yellow line in both the plan view and panoramic photo images of Figures 3.6 and 3.7 shows the newly created centerline feature using the reference plane method.



Figure 3.5 Illustration of reference plane method.

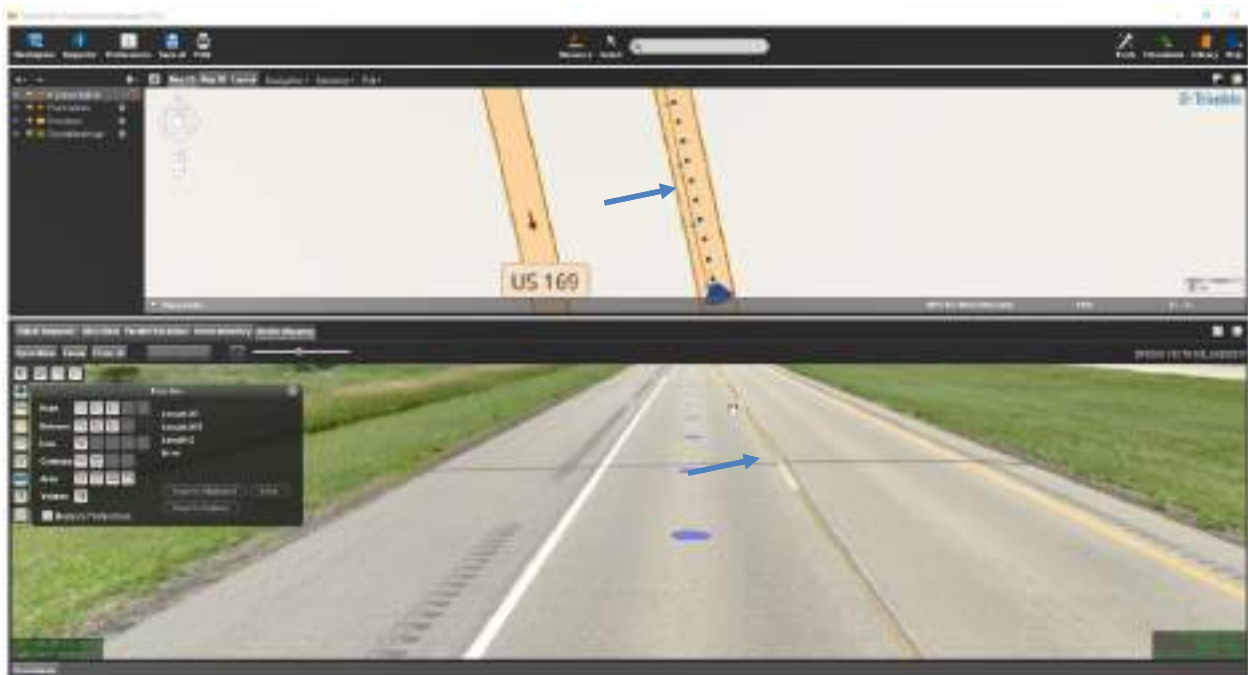


Figure 3.6 Image of centerline feature (fine, yellow line).

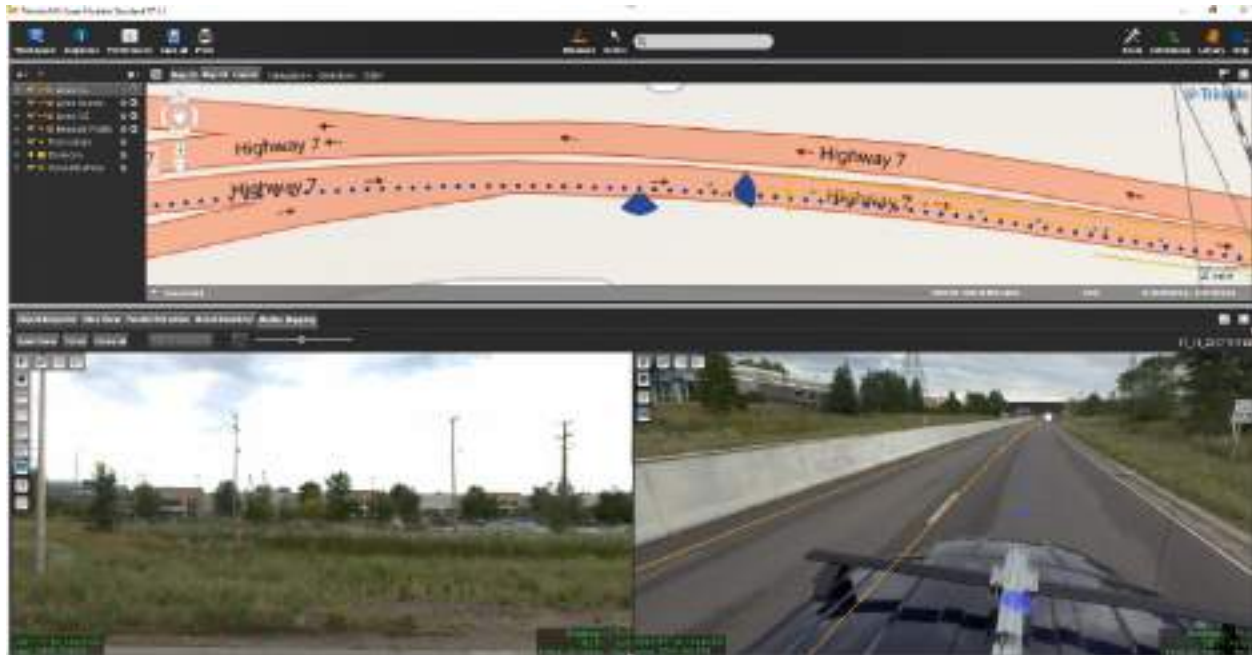


Figure 3.7 Second example of centerline feature resulting from reference plane extraction.

Again, the second extraction method used was the **forward intersection**. As shown in figures 3.5 through 3.7, the reference plane method uses one (1) panoramic image for identification of the given feature. However, with the forward intersection method, two different photo imagery views of the feature are used to extract the given feature to allow for increased horizontal accuracy. Figure 3.8 illustrates an image where the user is selecting the centerline feature using the forward intersection method. The user is able to see the selected feature simultaneously in both images (as the yellow dot) to allow for fine tuning of the selected image. Figure 3.9 illustrates the start of the creation of the centerline feature using the forward intersection method (yellow line) after multiple centerline feature selections. As previously noted, the use of this method requires additional time, however, it was desired to determine whether the magnitude of the increased accuracy and the additional time needed for this latter method is merited.



Figure 3.8 Image of selection of the feature using the forward intersection method.



Figure 3.9 Image of the creation of the centerline feature using the forward intersection method.

Figure 3.10 illustrates the resulting centerline feature extracted as a polyline with segment endpoints. This information is then be used by designers to create the needed alignment file(s) for the IC and PMTP methods.

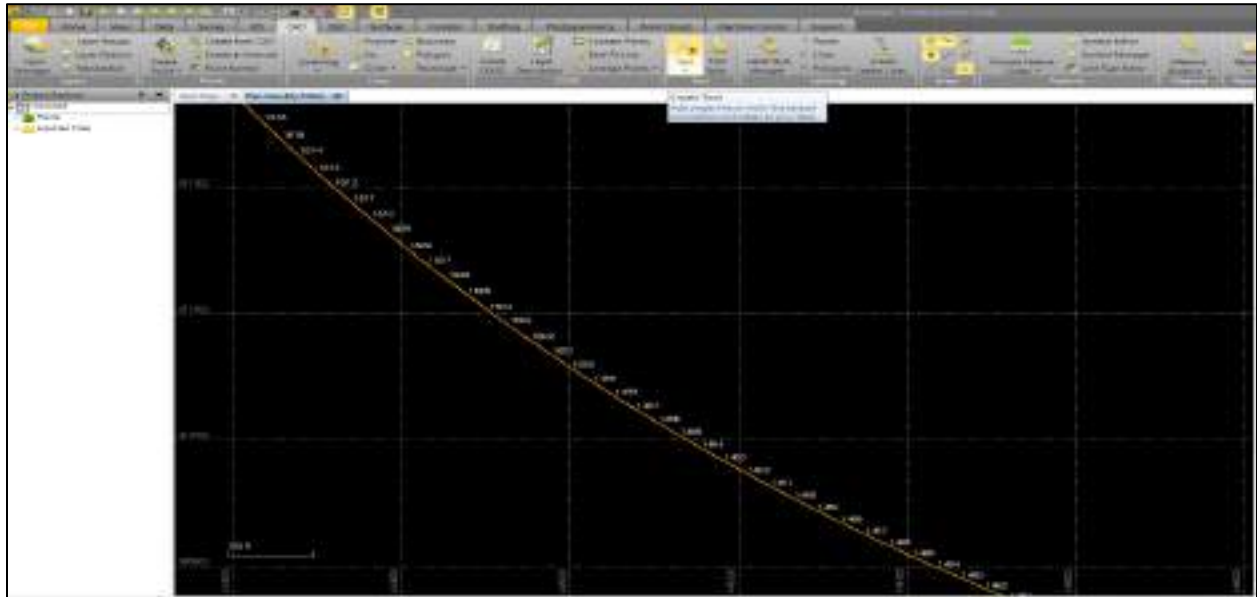


Figure 3.10 Image of centerline feature extracted as a polyline with segment endpoints.

3.2 ARCGIS CALCULATION OF POSITION ERRORS

The resulting features, extracted using the forward intersection and reference plane methods, were imported into ArcGIS in order to calculate the difference (position error) between the Trimble MX7 position locations verses conventional survey methods. As previously discussed, conventional survey methods were used to collect the in-place centerlines on past construction projects for creation of alignment files for the IC and PMTP methods. Consequently, a subset of these projects were chosen for comparison purposes with the Trimble MX7, since coordinates were already independently collected using conventional digital terrain methods (DTM), along with a project containing photo targets. See Appendix F for additional details on the use of ArcGIS for calculation of linear distance between the control points (conventional survey methods) and those generated by the Trimble MX7.

3.3 EVALUATION OF HORIZONTAL POSITION ACCURACY

As previously discussed, the photo targets installed on TH63 were used to determine the horizontal accuracy of the Trimble MX7 system and to evaluate the repeatability, effect of time of day and highway speeds on the horizontal accuracy. One hundred and fifty eight (158) photo targets were available on TH63 for use with LiDAR scanning that was being collected for creation of a 3D milling surface model for the upcoming construction project. Figure 3.11 shows a photo depicting the photo targets that were placed on the driving lanes of the roadway. Figure 3.12 shows where the PK nail was placed on each

photo target for the point of survey. Each PK nail had an associated X, Y, and Z coordinate, at ± 0.015 ft accuracy, that was compared to the Trimble MX7 mobile image at the same location.



Figure 3.11 Photo of TH63 photo target.

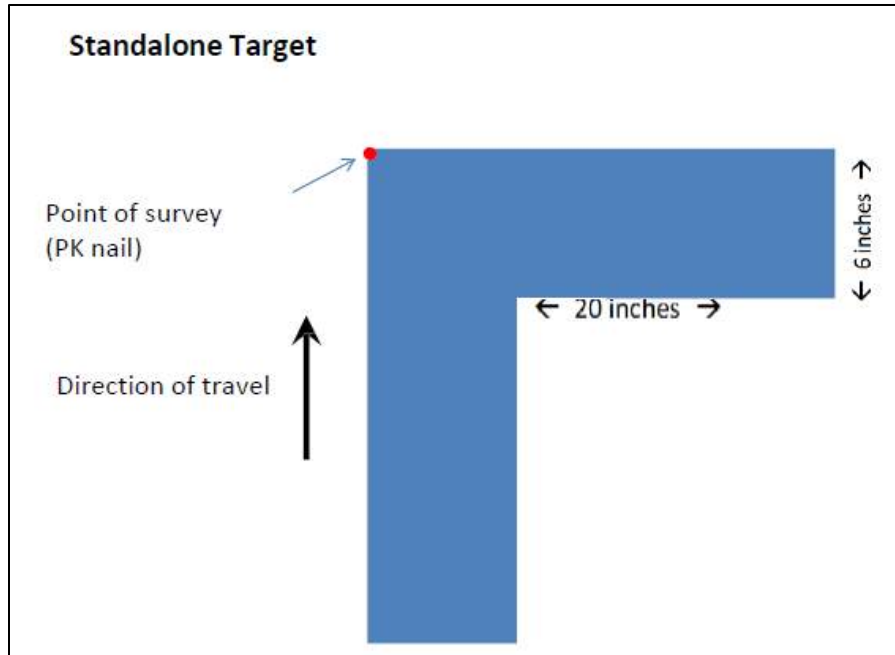


Figure 3.12 Image of PK nail on photo target for point of survey.

Mobile imaging was captured over these photo targets during two separate passes of the data collection vehicle. The PK nail coordinates obtained by the Trimble MX7 were then extracted using both the forward intersection and reference plane methods. Figure 3.13 illustrates the difference between the X-Y location of the Trimble MX7 and photo targets as determined using ArcGIS. As illustrated, there was greater variability and larger horizontal position errors using the reference plane method versus the forward intersection method. On average the difference between the Trimble MX7 and photo targets using the forward intersection and reference plane extraction methods was 0.26 ft (3.1 inches) and 1.1 ft (13.8 inches), respectively. While the 95 percent confidence interval for the forward intersection and reference plane extraction methods were determined to be: 0.2 ft (2.9 inches) to 0.3 ft (3.2 inches) and 1.0 ft (12.5 inches) to 1.3 ft (15.0 inches), respectively. Consequently, it was determined that the forward intersection method had significantly less position error when extracting the PK pin locations than the reference plane method. This was due to the ability to use the two side by side views of the images when extracting the features.

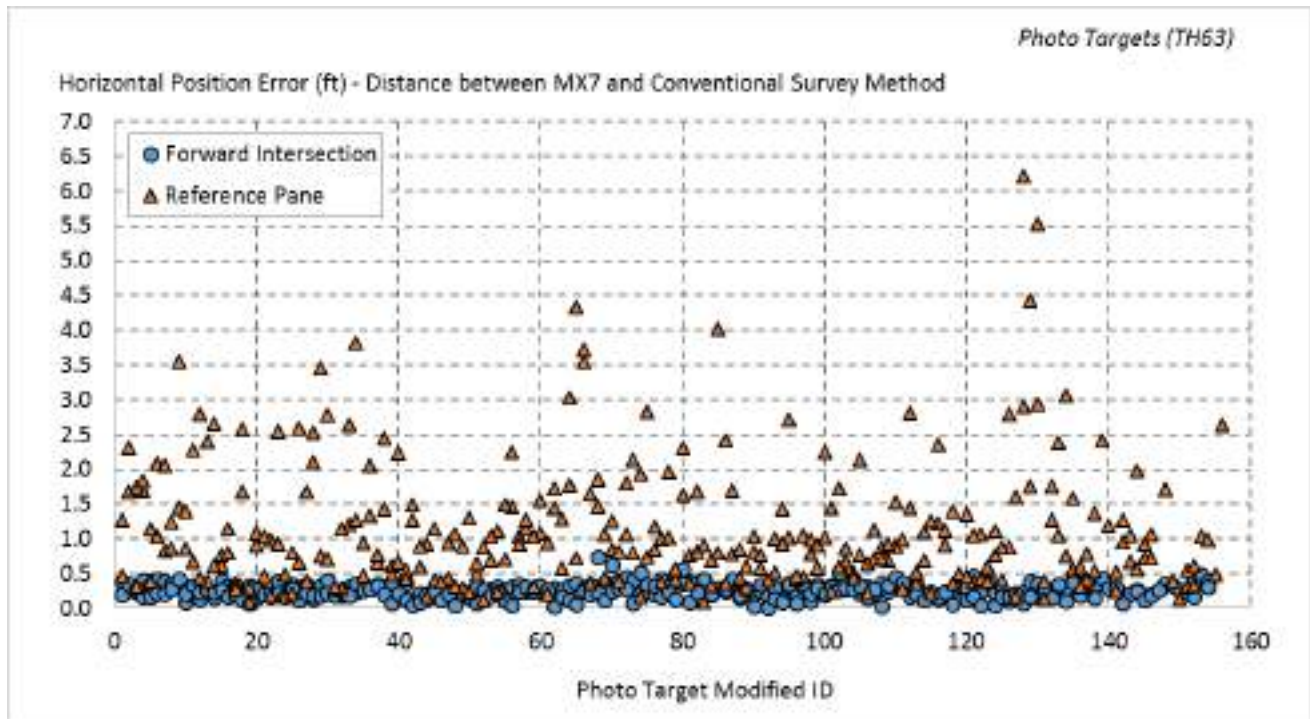


Figure 3.13 Graph of the effects of the extraction method on the Trimble MX7 position error.

Due to extraneous factors, the repeatability passes were not collected during the same time frame and were collected at speeds varying by 10 mph. The first repeatability pass was collected in the morning and the second was collected in the afternoon. Consequently, the effects of satellite location was also a factor when reviewing repeatability of the device. Figures 3.14 and 3.15 present graphs of the effects of repeatability and time (satellite location) on the Trimble MX7 results. As illustrated, there is a slight difference between the measurements collected from the first and second repeatability passes. This could be due to slight differences in selecting the PK pin from the images in the Trimble MX Asset Modeler software, the variation in data collection speed and/or the satellite locations during the data collections. Regardless, the position errors for both repeatability passes were well within the desired tolerances (≤ 4 inches) needed for creation of centerline alignment files for the IC and PMTP methods.

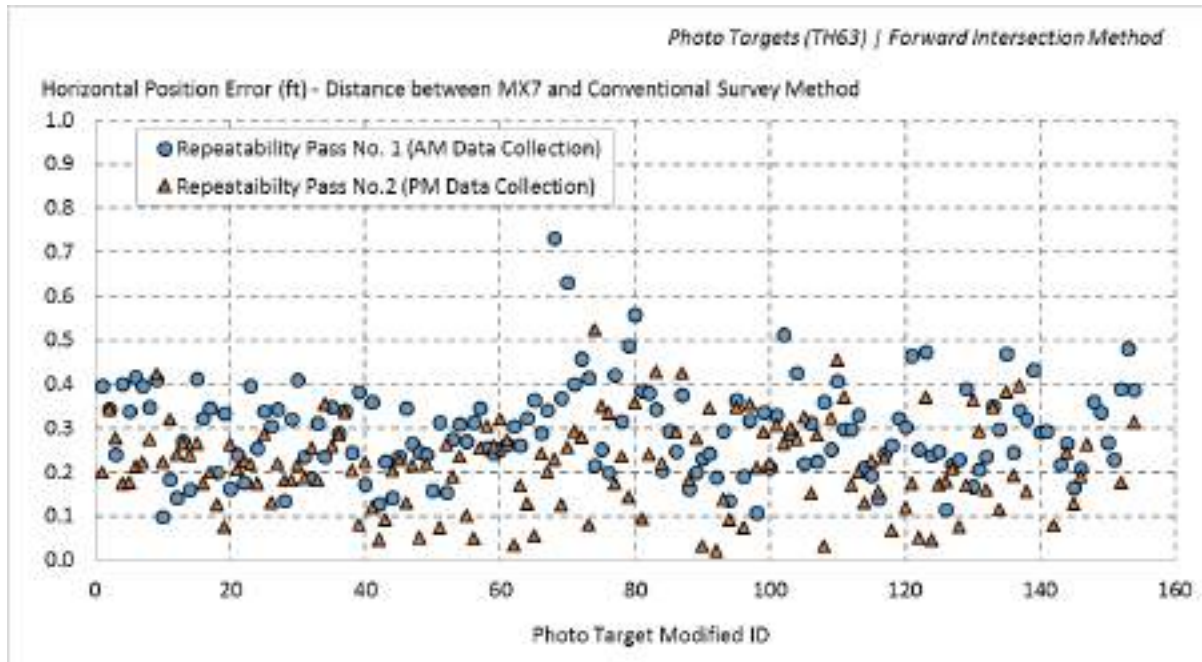


Figure 3.14 Graph of the effects of repeatability and satellite locations on the MX7 position error.

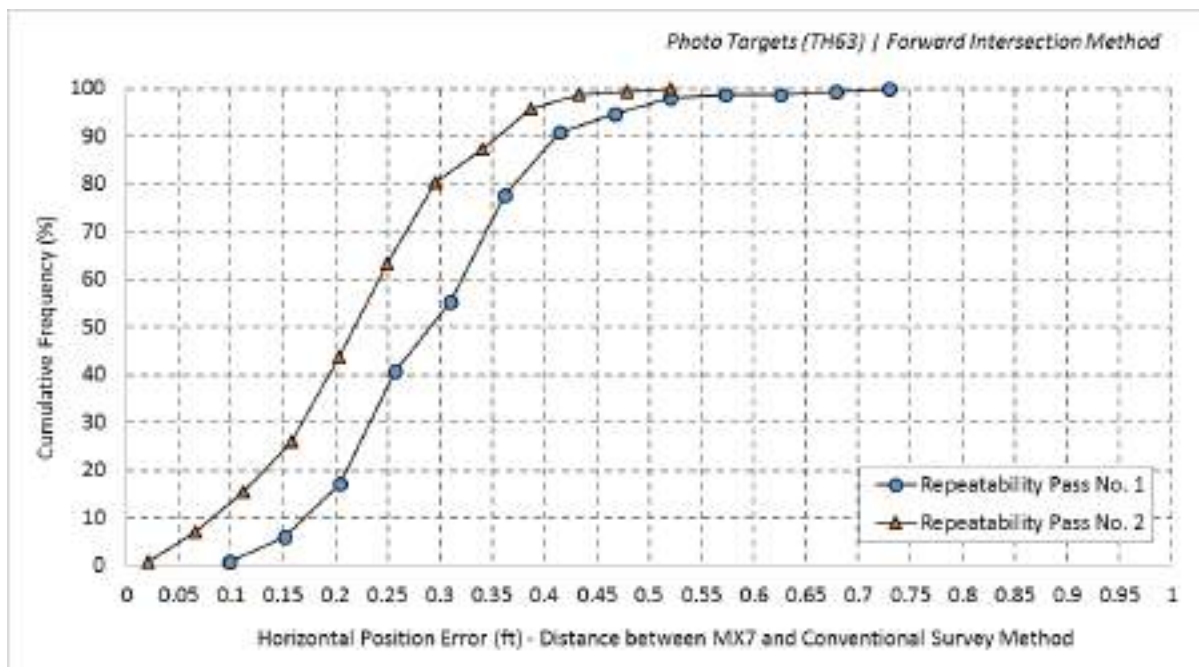


Figure 3.15 Cumulative distribution graph of the effects of repeatability and satellite locations on the MX7 position error.

3.4 STATEWIDE PROJECT VALIDATION OF POSITION ACCURACY

Further validation of the Trimble MX7 horizontal position accuracy was completed on the projects listed in Table 2.1. These projects did not contain photo targets, however, the district survey units had already

collected the in-place centerline using conventional survey methods. Consequently, points were extracted from these alignment files for comparison with the Trimble MX7 extracted centerline feature.

Please note that the following summarizes the results from two of these projects. Similar results were obtained with the remaining projects.

As with the photo target analyses, the reference plane and forward intersection extraction methods were used to extract the in-place centerline as collected by the Trimble MX7. Plan view maps were generated in ArcGIS to illustrate the horizontal position error (i.e., the distance between the in-place centerline as measured using conventional survey methods versus the in-place centerline extracted from the Trimble MX7 mobile images). Figure 3.16 illustrates an example of the plan view map generated for TH27. The offset distance listed in this image reflects the position error. These maps were used to investigate possible causes of larger position errors. For this example, no real trend for the localized areas with higher position error was apparent. However, Figure 3.17 illustrates an example where tree canopies might have caused these higher position errors. The red and orange colors in this plan view map indicate position errors that were 0.61 ft (7.3 inches) or greater. As illustrated, a tree canopy was present over the roadway at these locations that can potentially affect location accuracies.

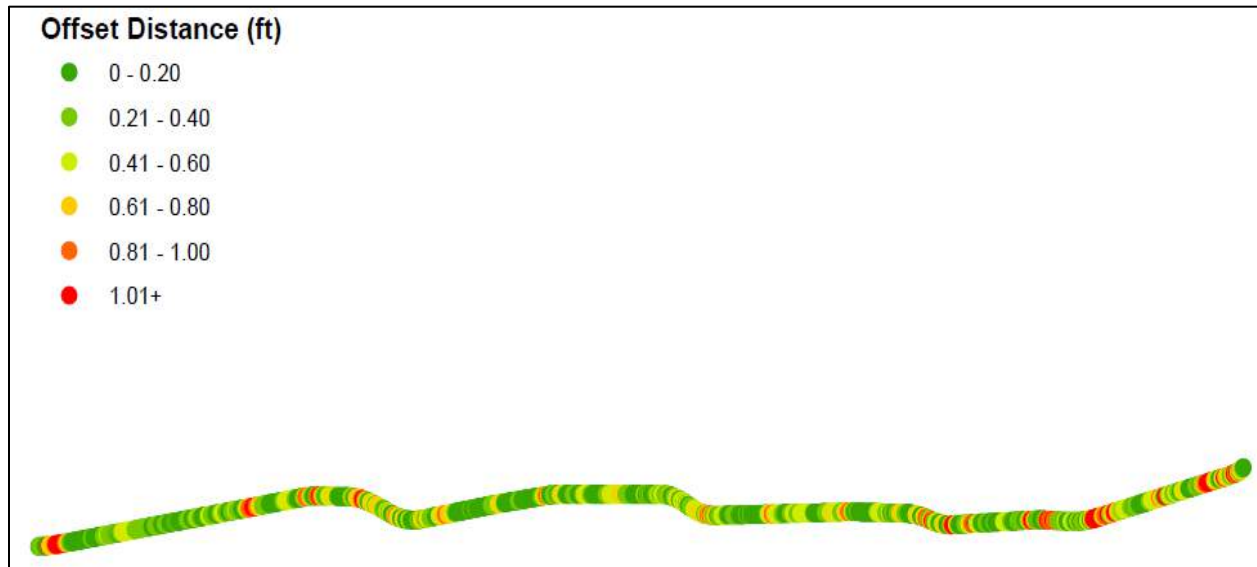


Figure 3.16 Plan view map of the Trimble MX7 position error using the forward intersection method (TH27).



Figure 3.17 Plan view map of Trimble MX7 higher position error under tree canopies (TH3, forward intersection extraction).

Cumulative distribution graphs were generated for the projects to further determine whether the accuracy of the Trimble MX7 is within the levels needed for generation of alignment files for the IC and PMTP methods. Figures 3.18 and 3.19 show examples of these distribution graphs for TH27 and TH3, respectively. Please note, that TH3 was chosen as an example due to the large amount of tree canopy present within the project limits. The average position error for TH27 using the reference plane and forward intersection extraction methods was determined to be 0.6 ft (7.7 inches) and 0.4 ft (4.6 inches), respectively. Similar values were also obtained on TH3, where the average position error for the reference plane and forward intersection extraction methods were 0.7 ft (8.0 inches) and 0.4 ft (4.7 inches), respectively. Similar position error results were found on the remaining projects.

This validation process also indicated similar results to that of the photo target verification, that the forward intersection extraction method provides an increased horizontal accuracy when determining feature point locations than the reference plane method. However, the overall accuracy of the results was slightly greater when looking at the photo target comparisons, in lieu of the in-place alignment. The average position errors were 0.26 ft (3.1 inches) and 0.4 ft (4.6 inches) for the comparisons with the photo targets and in-place alignment, respectively. This is most likely due to the lack of consistency in what was considered the “in-place” centerline when collecting the DTM of the centerline using

conventional survey methods. For instance, which portion of the skip line was considered the in-place centerline (e.g., left edge, right edge, middle), or whether the cold joint was used.

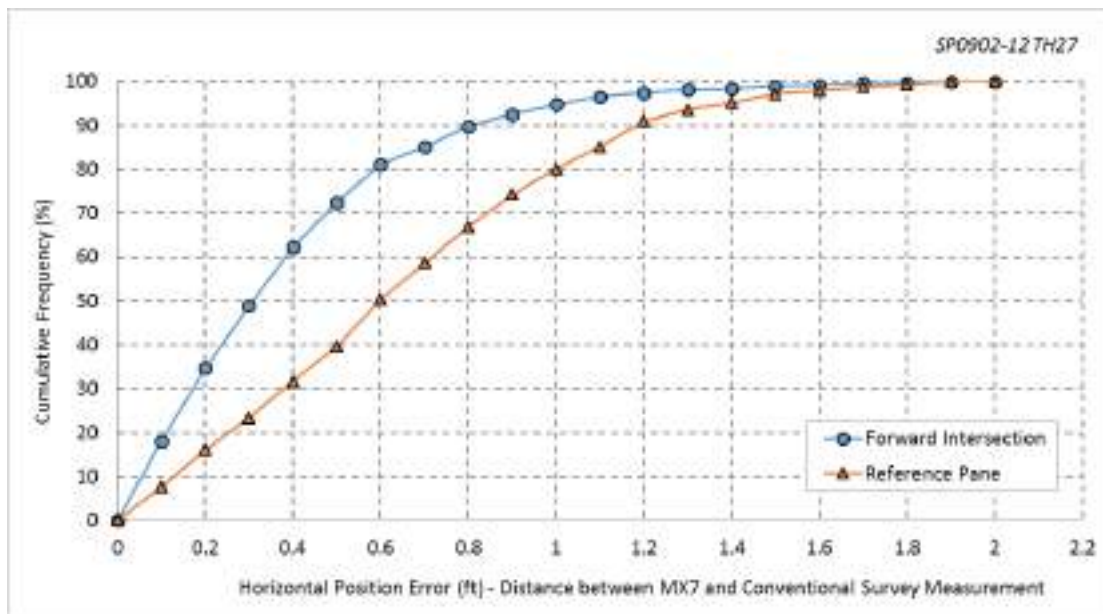


Figure 3.18 Cumulative distribution graph of position errors for TH27.

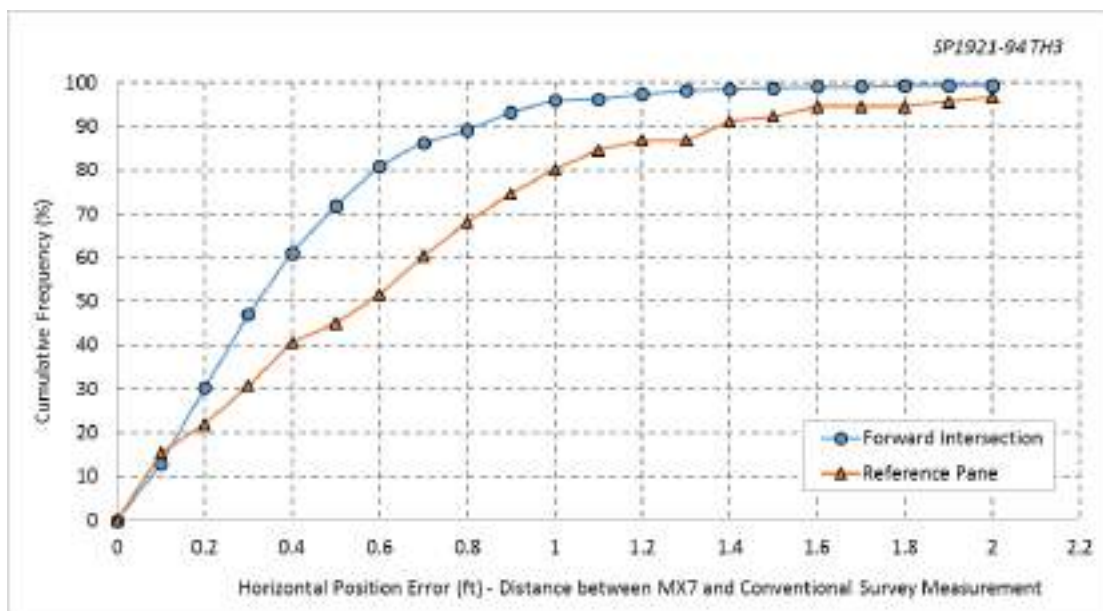


Figure 3.19 Cumulative distribution graph of position errors for TH3.

3.5 TRIMBLE BUSINESS CENTER SOFTWARE ENHANCEMENTS

Enhancements were made to the Trimble Business Center software since the purchase of the Trimble MX7 system. These enhancements allow the feature extractions to be conducted within Trimble

Business Center in lieu of the Trimble MX Asset Modeler software, thereby, eliminating the need to purchase a licensed copy of Trimble Asset Modeler and to learn how to run this software. Known point comparisons were conducted utilizing a subset (44 percent) of the photo target locations on the TH63 project. Figures 3.20 and 3.21 present graphs of the horizontal position error with respect to the given software. As illustrated, the results show that the Trimble Business Center software performs with the same accuracy, if not slightly more accurate, as that of the Trimble MX Asset Modeler Software. The average position error using the forward intersection method from Trimble Business Center and the Trimble MX Asset Modeler software was found to be 0.20 ft (2.4 inches) and 0.26 ft (3.1 inches), respectively. While the 95 percent confidence interval for the forward intersection method using Trimble Business Center and Trimble MX Asset Modeler software was determined to be: 0.18 ft (2.1 inches) to 0.22 ft (2.7 inches) and 0.2 ft (2.9 inches) to 0.3 ft (3.2 inches), respectively. As previously noted, 44 percent of the photo targets were assessed for verification of the extractions through Trimble Business Center due to time constraints. This smaller sample population could potentially affect the slight variation in position errors between the two software platforms. Regardless, the position error accuracy was well within the desired limits (≤ 4 inches) for creation of alignment files for the IC and PMTP method using the new enhancements in Trimble Business Center. Consequently, it is recommended that this software is used in the future in lieu of the Trimble MX Asset Modeler software to decrease the number of software platforms required for extractions.

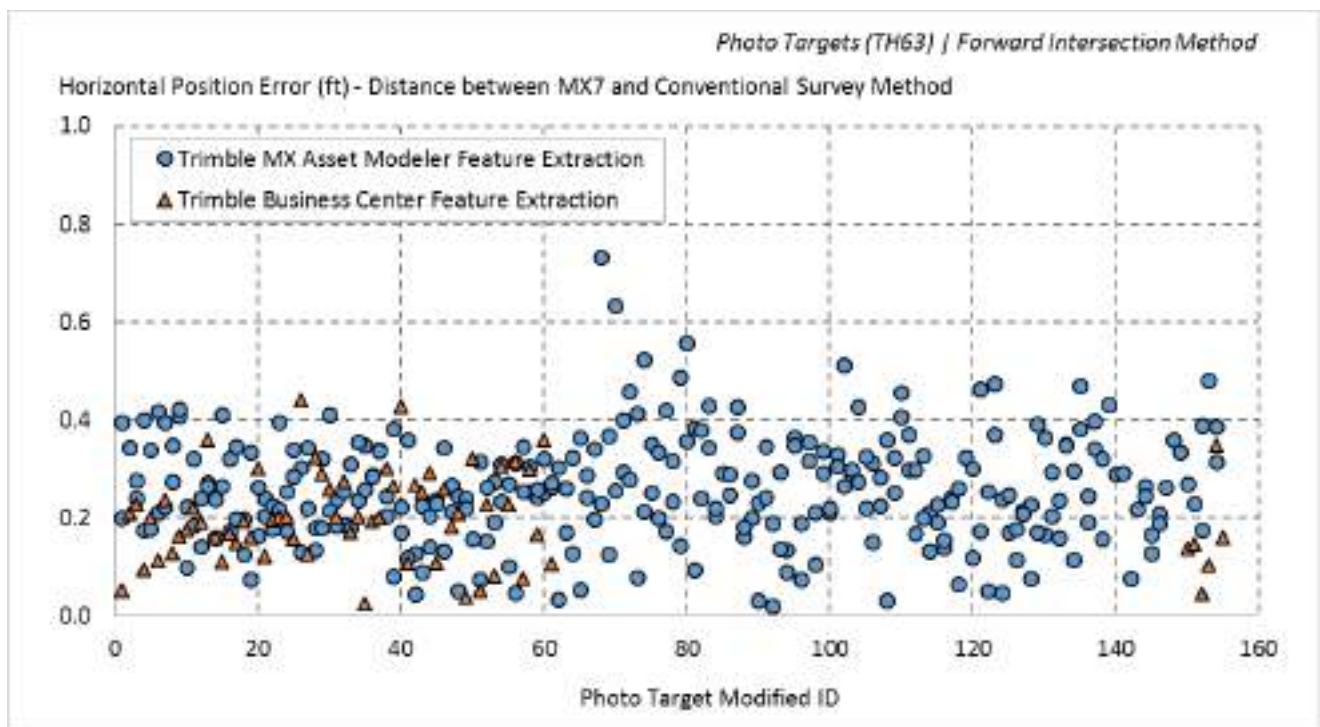


Figure 3.20 Graph of horizontal position error for the Trimble MX Asset Modeler and Trimble Business Center software.

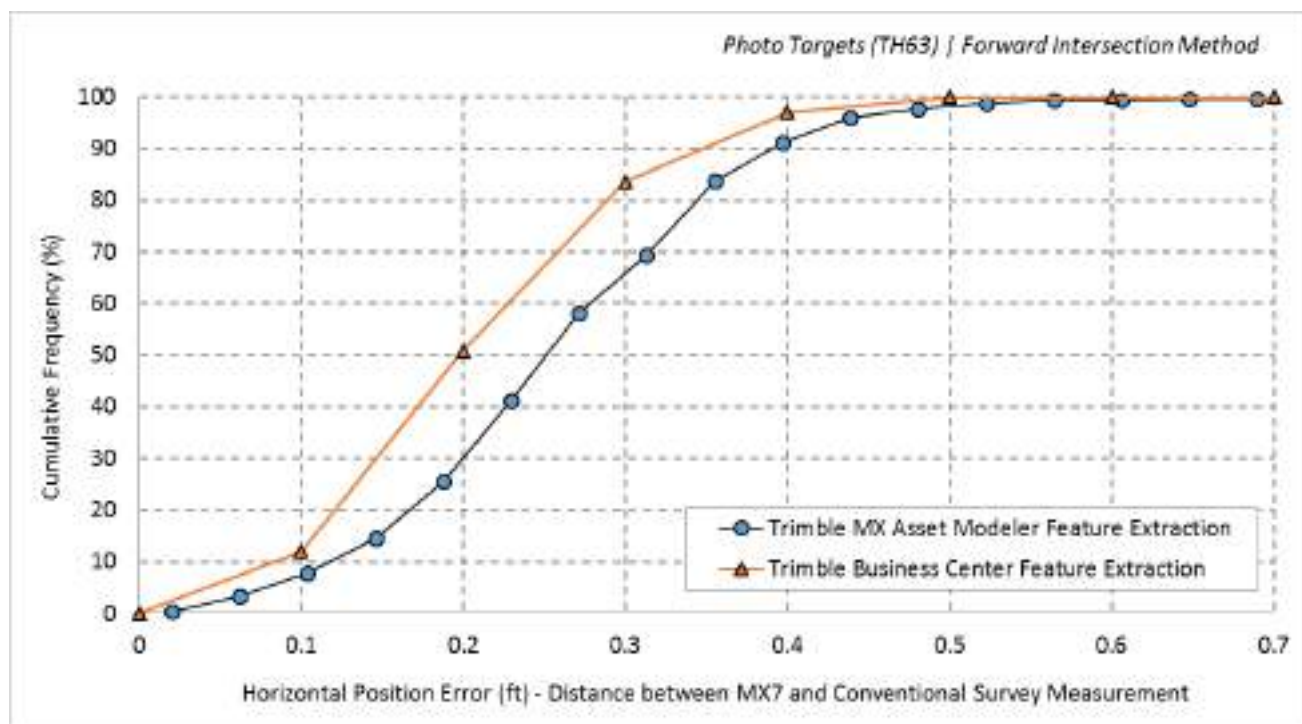


Figure 3.21 Cumulative distribution graph of horizontal position error for the Trimble MX Asset Modeler and Trimble Business Center software.

CHAPTER 4: CONCLUSIONS, RECOMMENDATIONS AND CURRENT DEPLOYMENT

4.1 CONCLUSIONS

The following summarizes the conclusions resulting from verification of the accuracy of the Trimble MX7 system:

- Installation of the Trimble MX7 system can be completed with relative ease.
- Use of the various software platforms (i.e., POSPac, Trimble Business Center, Trimble MX Asset Modeler) was completed without any issues.
- System and software training, provided by Frontier Precision and a Trimble Certified Trainer, respectively, was extremely beneficial and warranted.
- Processed data file sizes are a concern for future storage of this information as part of asset management. Processed data files sizes are approximately 3.5 GB per centerline mile. Storage of raw data files will require even greater storage space.
- The Trimble MX7 has the needed accuracy for capturing the in-place centerlines for creation of alignment files for the IC and PMTP methods.
- Satellite configurations (time of day) and data collection speed did not appear to significantly affect the results as determined from comparisons with photo targets and the statewide assessment where collection times and locations significantly varied.
- On average, the position error of the Trimble MX7 trajectory in the X, Y, and Z direction was found to be 2, 2 and 3 cm, respectively.
- Extraction of the features using the forward intersection method was more accurate (i.e., has less horizontal position error) than that found using the reference plane method. On average the difference between the Trimble MX7 and photo targets using the forward intersection and reference plane extraction methods were 0.26 ft (3.1 inches) and 1.1 ft (13.8 inches), respectively. While the 95 percent confidence interval for the forward intersection and reference plane extraction methods were determined to be 0.2 ft (2.9 inches) to 0.3 ft (3.2 inches) and 1.0 ft (12.5 inches) to 1.3 ft (15.0 inches), respectively.
- Similar position error results to that found with the photo targets were also found when comparing the Trimble MX7 positions to alignment files created (across the state) using conventional survey methods.
- Enhancements made to the Trimble Business Center software now allow for feature extractions through this platform in lieu of Trimble MX Asset Modeler. The average position error using the forward intersection method from Trimble Business Center and the Trimble MX Asset Modeler software was found to be 0.20 ft (2.4 inches) and 0.26 ft (3.1 inches), respectively. While the 95 percent confidence interval using the forward intersection method using Trimble Business Center and Trimble MX Asset Modeler software was determined to be 0.18 ft (2.1 inches) to 0.22 ft (2.7 inches) and 0.2 ft (2.9 inches) to 0.3 ft (3.2 inches), respectively.

4.2 RECOMMENDATIONS

The following summarizes recommendations resulting from verification of the accuracy of the Trimble MX7 system:

- The Trimble MX7 can be used to capture the in-place centerline for use in creation of alignment files for the IC and PMTP methods.
- The forward intersection method should be used for extraction of features (i.e., in-place centerlines) in lieu of the reference plane method.
- Trimble Business Center can be used to extract features in lieu of the Trimble MX Asset Modeler software.
- Long-term storage options should be considered for storage of the mobile imaging files.
- Districts can use the Trimble MX7 to capture other needed assets, in addition to the in-place centerlines (e.g., locations of mailboxes, guardrails, signs, catch basins, etc.; bridge clearance heights, linear lengths of given assets, etc.).

4.3 CURRENT USE

There has been an increased interest in the use of the Trimble MX7, as districts have been receiving education on the capabilities of the Trimble MX7. The following subsections summarize some of the current uses of the system to date.

4.3.1 District 1

District 1 contacted the Advanced Materials and Technology (AMT) unit to assist with establishment of an in-place alignment for TH73 from Cromwell to Hibbing. The route was collected and post processed within two (2) days of the request due to the ease of this technology. The AMT unit completed the forward intersection extractions and provided the district with an in-place centerline location every ± 25 ft for the entire corridor within three (3) days. The district then generated an alignment file for use with the IC and PMTP methods for the 2018 and 2019 construction seasons.

4.3.2 District 3

District 3 decided to move forward with using the system to collect in-place centerlines on four routes that have IC and PMTP during the 2019 construction season. The system was delivered to the district along with training on the setup and collection procedures. This training included a ride-along data collection for one (1) of the four (4) routes, along with training on the extraction of data. The remaining three (3) routes were collected by District 3 in one (1) day. The AMT unit post processed the four (4) routes through the POSpac software and extracted the in-place centerline feature, using Trimble Business Center, for one (1) of the four (4) projects as part of the training process. The district will complete the remaining in-place centerline feature extractions. (Please note that Frontier precision has created a video on the use of Trimble Business Center for extraction of data that was shared with the district.)

The district surveyors stated that they were extremely impressed with how easy the data collection process was to execute.

4.3.3 District 7

District 7 requested the use of the Trimble MX7 system to collect mobile imaging on 17 upcoming projects that will be constructed during the next four (4) years. A meeting with the district was held to show the capabilities and overview of the system. The district decided to move forward with the use of the system. Training on the setup of the system and collection procedures was provided by the AMT unit. The initial training included a ride-along collection for one (1) of the above mentioned routes. These projects were collected for alignment file creation and pre-scoping purposes. Another meeting was established for training on the processing of data, after the data collection of the 17 routes was completed. The AMT unit processed all of the projects using the POSPac software. The district was then instructed on the processing of the panoramas, using Trimble Business Center, for creation of the panorama and trajectory *.csv files. A meeting will be scheduled between the AMT unit and the district, after the projects are processed through Trimble Business Center, to provide instruction on how to complete the feature extractions using the forward intersection method in Trimble Business Center.

APPENDIX A

TRIMBLE MX7 EQUIPMENT SETUP

The following outlines the procedure for setup of the Trimble MX7 system.

1. Ensure that all of the Trimble MX7 system components are present (see Figure A.1).

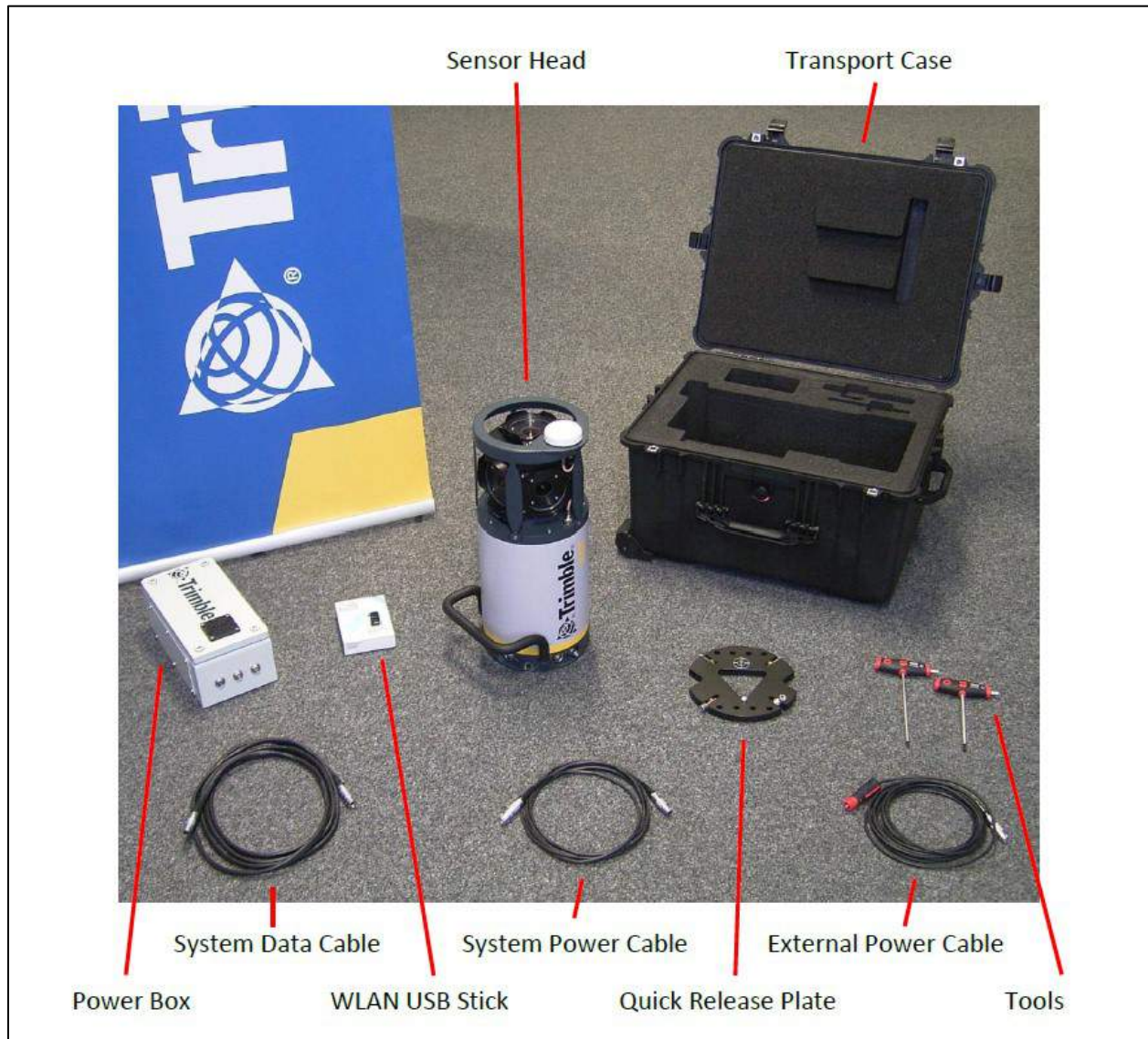


Figure A.1 Photo of the Trimble MX7 system components.

2. Install the cargo rack to the top of the collection vehicle. Ensure that the camera has a full 360 degree view without any obstructions. Verify that the rack is secure.
3. Measure the height from the ground plane to the top of the Trimble MX7 quick release plate as accurate as possible (write down for future reference). See figure A.2.

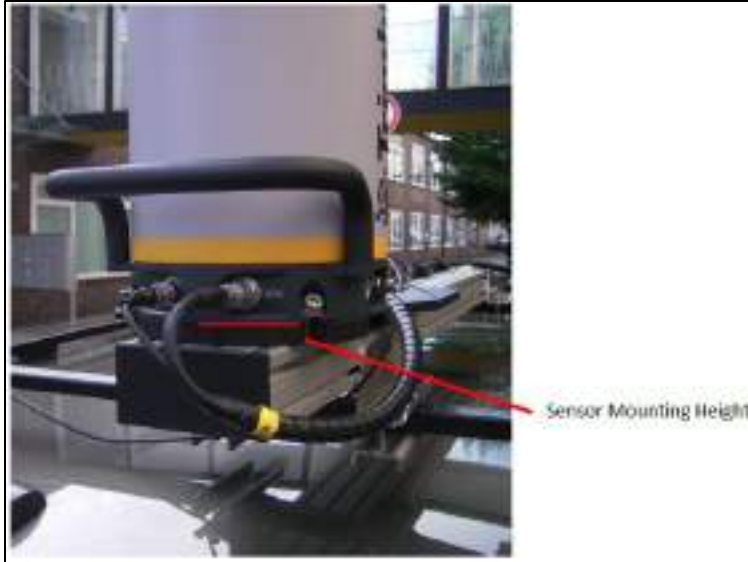


Figure A.2 Photo of sensor mounting height.

4. Install the Trimble MX7 unit to the base plate on the mounting rack (use alignment pin on the base plate to align properly). Ensure that the handle on the MX7 unit is facing the rear of the vehicle (see figure A.2.b). Use an allen wrench to securely tightening the four (4) allen screws to the MX7 (see figure A.3).



Figure A.2.b Photo of MX7 unit handle.



Figure A.3 Photos of allen screws on MX7.

5. Connect the power and data cables (two long cables) to the MX7 and power converter unit (see figures A.4 through A.7). Secure the cables by wrapping them around the cargo rack a few times and route them into the vehicle to connect to the power converter unit.



Figure A.4 Photo of power cable to be connected between the MX7 and power converter unit.



Figure A.5 Photo of the data cable to be connected between the MX7 and power convert unit.



Figure A.6 Photo of Trimble MX7 Sockets for the power and data cables.



Figure A.7 Photo of 12V-IN power and system data sockets on power converter unit.

6. Connect the final cable from the power converter unit to the vehicle 12V power supply.



Figure A.8 Photo of power cable to be connected between power converter unit and vehicle.

7. Connect the WLAN USB stick to one of the two USB ports on the power converter unit.



Figure A.9 Photo of WLAN USB stick and USB ports.

APPENDIX B

MOBILE IMAGING DATA COLLECTION PROCEDURE

The following outlines the procedure for collecting the mobile imaging data using the Trimble MX7.

1. Turn on the vehicle and leave the vehicle running until the system is properly shutdown after the data collection.
2. Turn on the power button for the power converter unit and allow a couple of minutes for the system to startup.
3. Power on the tablet to access the user interface.
4. Select the internet icon on the iPad (e.g., Safari) and the WebUI will then automatically start (see figure B.1). The following three (3) menu options are displayed:
 - 4.1 Mission – the mission menu starts a new mission to collect data.
 - 4.2 Backup Data – the backup data menu allows the user to save the data to an external storage device.
 - 4.3 Settings – the settings menu contains the settings and parameters for system setup and data collection to be adjusted by the user.

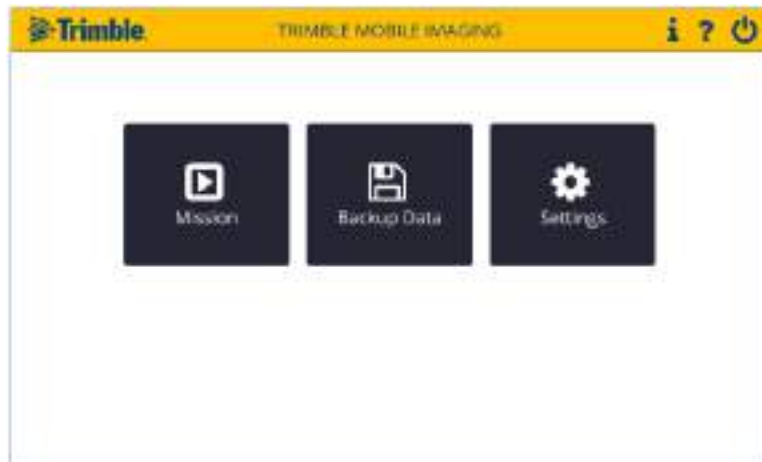


Figure B.1 Image of WebUI startup screen.

5. Select the settings menu button in the WebUI (see figure B.2).

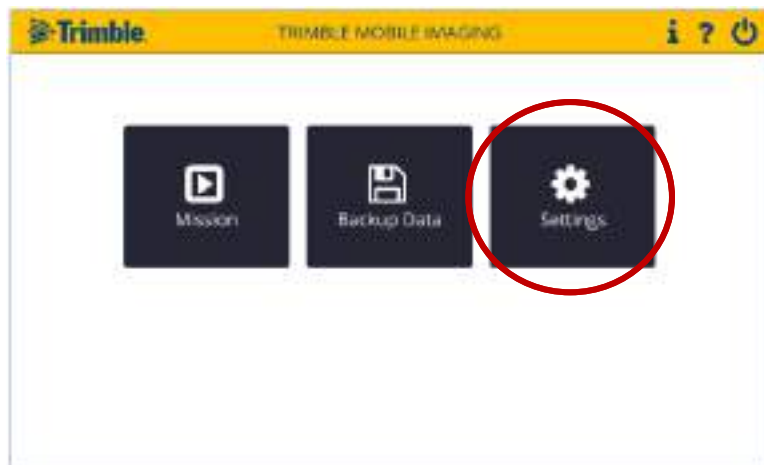


Figure B.2 Image of settings menu icon.

6. Select new from the vehicle field (see figure B.3). The same vehicle settings can be used for subsequent data collection events, however, ensure that the sensor mounting height is correct. Use the edit button to modify existing settings as needed.

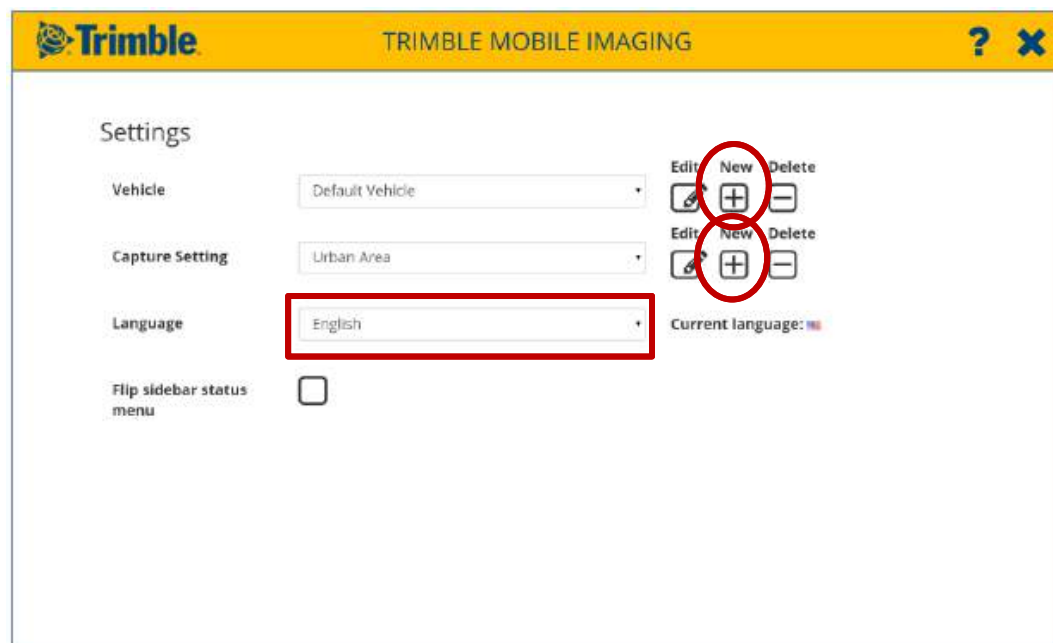


Figure B.3 Image of settings screen.

7. Enter the vehicle settings (see figure B.4):
 - 7.1 Name the vehicle.
 - 7.2 Enter a brief description (optional).

- 7.3 Enter the height of the base plate (previously measured), in the units of meters, in the install height field.

Trimble TRIMBLE MOBILE IMAGING ? X

Edit Vehicle Setting

Name:
Default Vehicle

Description:
Example Description

Installation Parameter

Install Height:
2

☐ Revert Installation

DMI

☐ Use DMI

GAMS

☐ Use GAMS

Figure B.4 Image of vehicle settings screen.

8. First time users of the software, will need to create a capture setting of the camera. Select new from the Capture Setting Field (see figure B.3). This capture setting can be selected for future use. **Edit** the capture settings as follows (see figure B.5):
- 8.1 **Name** the capture setting. For this example “Rural Area” was used.
- 8.2 Select the **Distance Based** setting for the camera trigger type. This trigger type defines the distance interval (in meters) at which the camera will be triggered. The Fixed Frame Rate triggers the camera at preset time intervals.
- 8.3 Set the **Trigger Distance** to 4 meters. Four meters should be adequate for most cases. Adjust as needed for other applications.
- 8.4 Select **Ignore Navigation Status** and **Outdoor** (GNSS required) in the advanced settings.
- 8.5 Select **Save**.

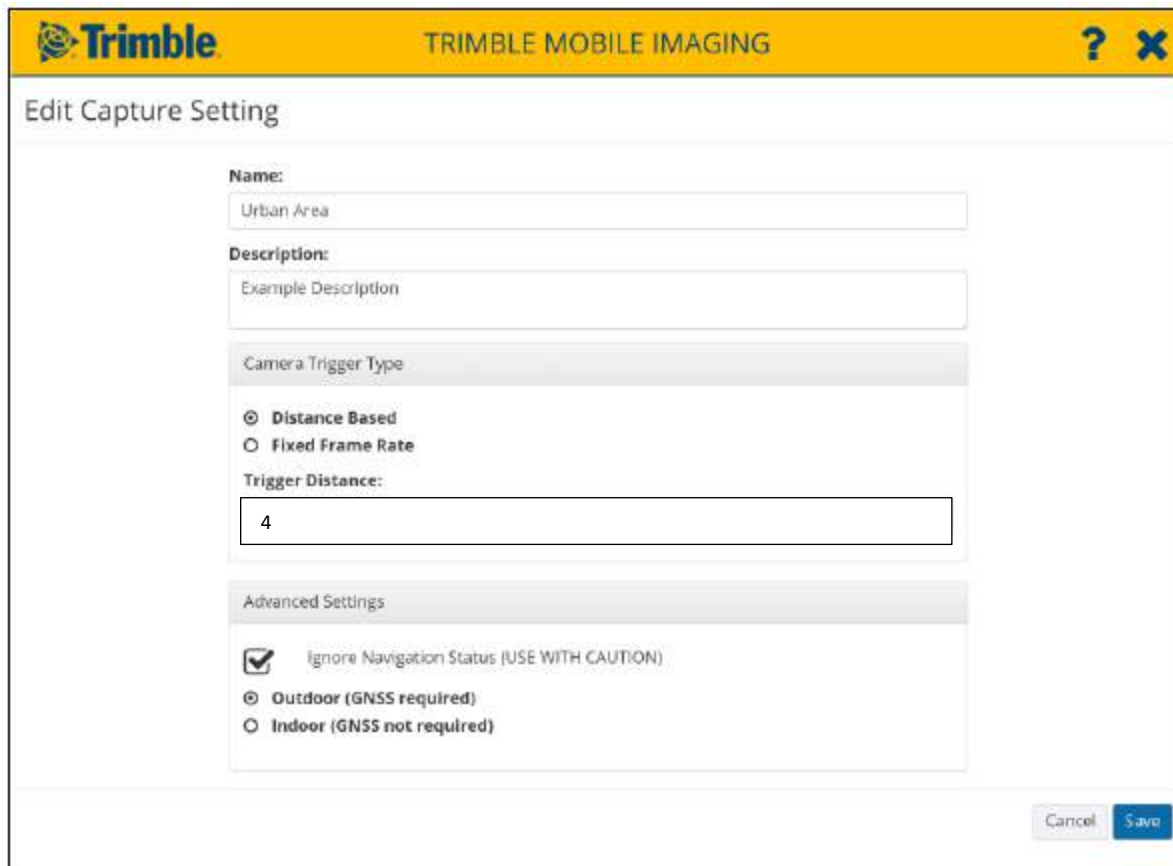


Figure B.5 Image of edit capture settings screen.

9. Set Language to English (see figure B.3).
10. Select the “X” in the upper right corner to close the settings screen.
11. Select the Mission Menu Button from the main menu screen (see figure B.6).

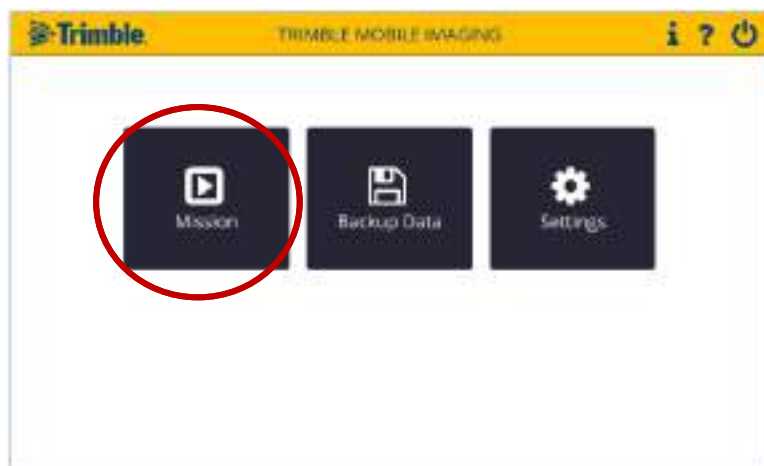


Figure B.6 Image of Mission icon on main menu screen.

12. Enter the following information in the mission setup menus (see figure B.7):
 - 12.1 Name the mission using the date, route number and direction of travel.
 - 12.2 Select the capture setting by choosing Rural Area (the capture setting created in step 8).
 - 12.3 Select the Vehicle that was previously created in step 7.
 - 12.4 Select the NEXT button to prompt a window to confirm the presets.



Figure B.7 Image of Mission Setup details.

- 12.5 Review the information, if everything is correct select **Start**, however, ensure that the vehicle is in motion before choosing start (see figure B.8). It is recommended that the start and end times of the data collection are also documented.

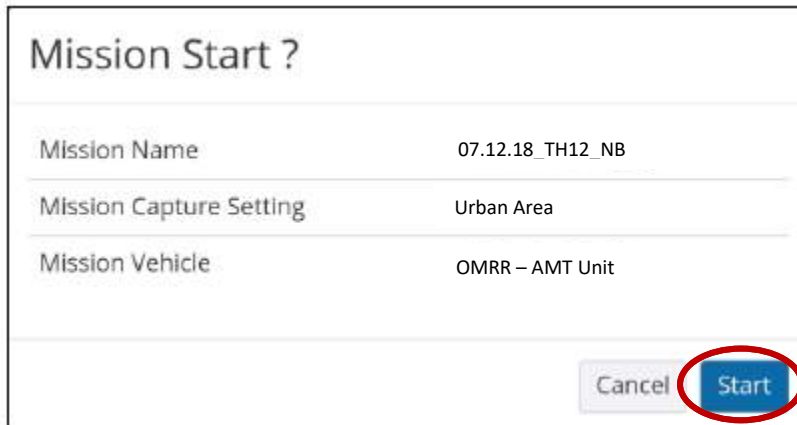


Figure B.8 Image of Mission Start confirmation.

13. After selection of start, the collection screen will appear and the navigation icon will show red (see figure B.9). Tap on the navigation icon to view the Accuracy status.

Start driving until all 4 **Arrows** (i.e., heading, attitude, position and velocity) are in the green area and the **Navigation** icon turns green (see figure B.10).

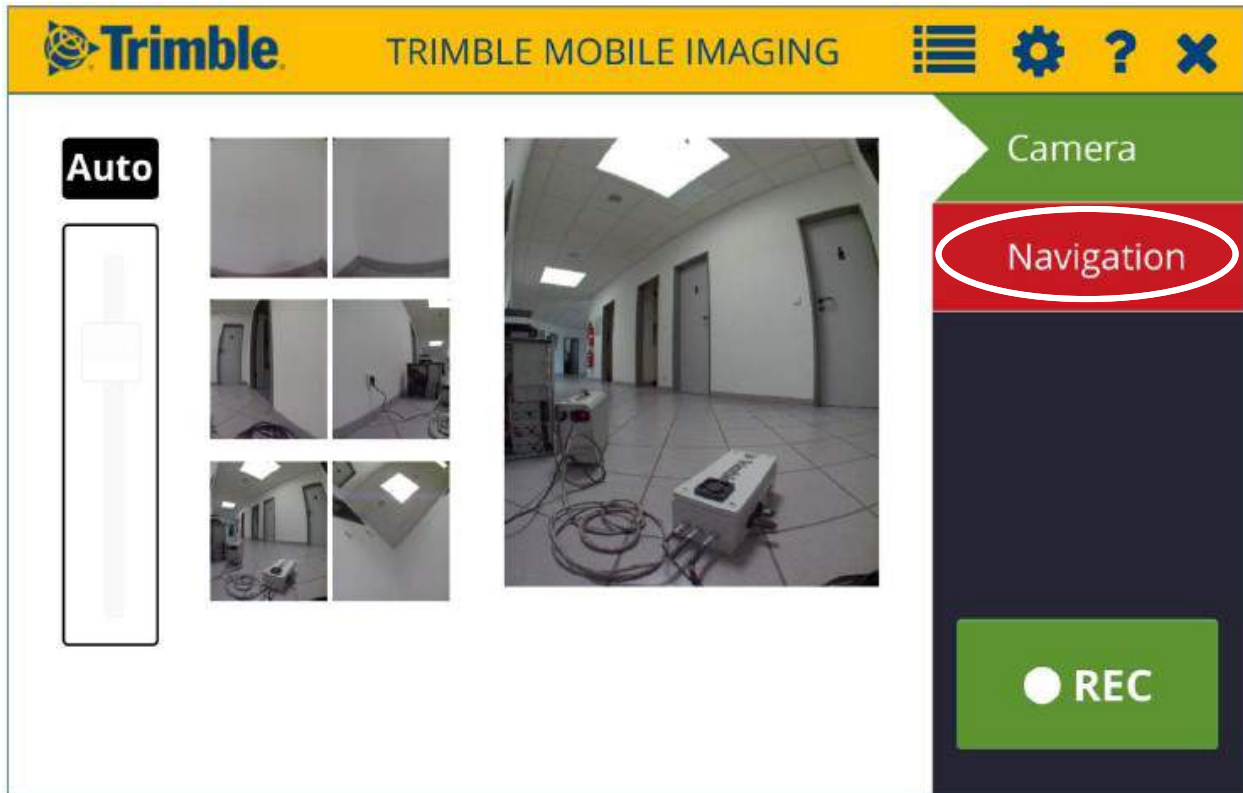


Figure B.9 Image of Trimble mobile imaging capturing screen.



Figure B.10 Image of navigation accuracy.

14. Once the navigation icon turns green you are ready for data collection. Proceed to the area of collection and choose **REC** to start recording. Please note that the user can select the camera icon, located above navigation, to view the cameras during collection.
15. Select **Stop** after completion of the data collection.
16. Choose the "X" in the upper right corner to complete the mission and then select the complete mission button (see figure B.11).

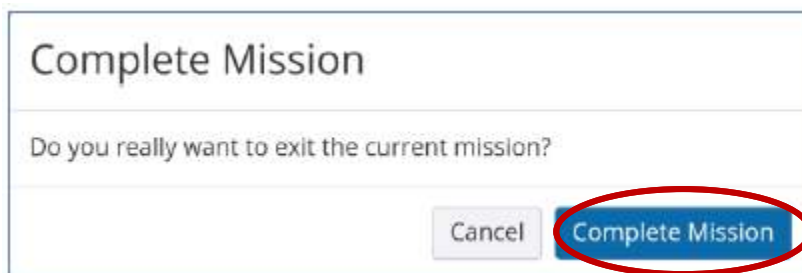


Figure B.11 Image of complete mission button.

17. Connect the external HD to the MX7 unit via USB port and select backup data from main menu (see figure B.12).

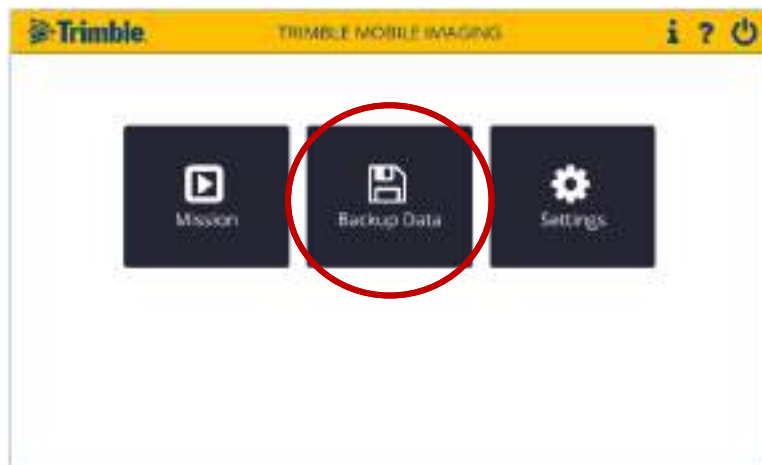


Figure B.12 Image of backup data icon.

18. Verify the external HD is recognized and select the empty box next to the mission that was just collected and select **start backup** (see figure B.13).

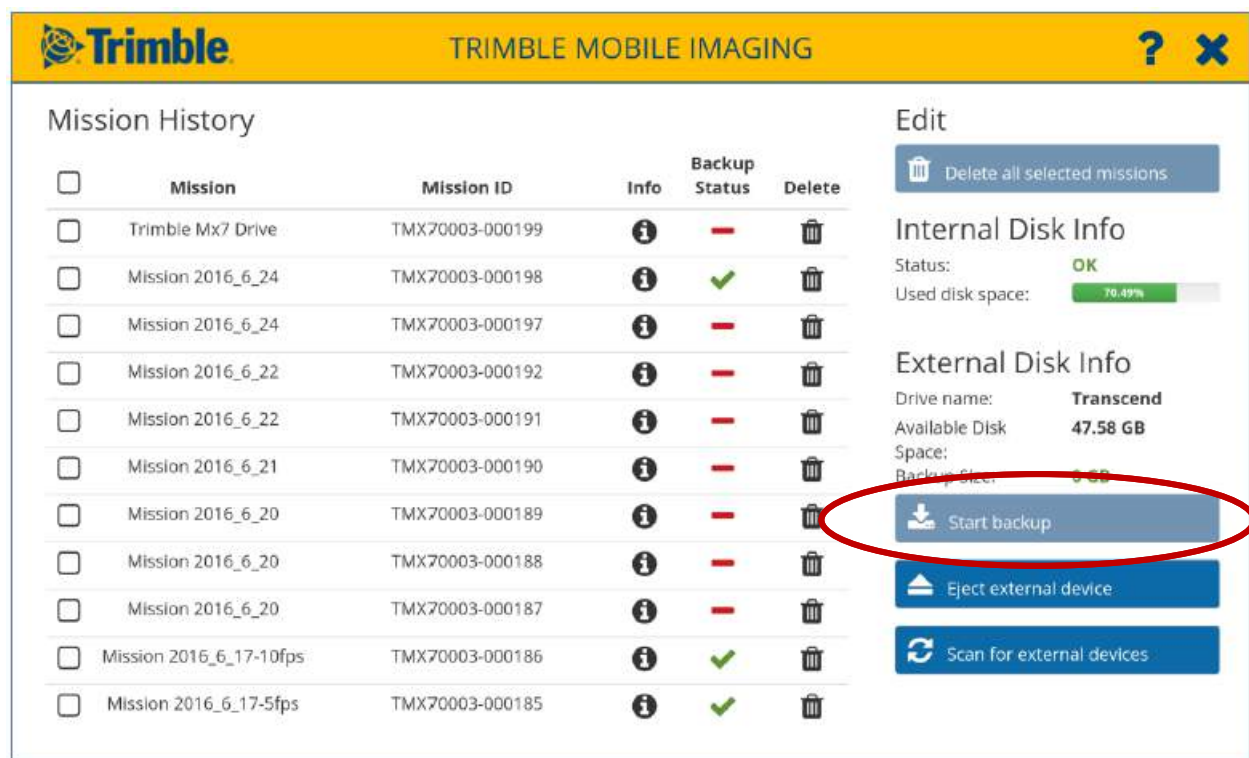


Figure B.13 Image of mission history and external disk information.

19. A progress window will show the status of the backup. When complete select **OK**.

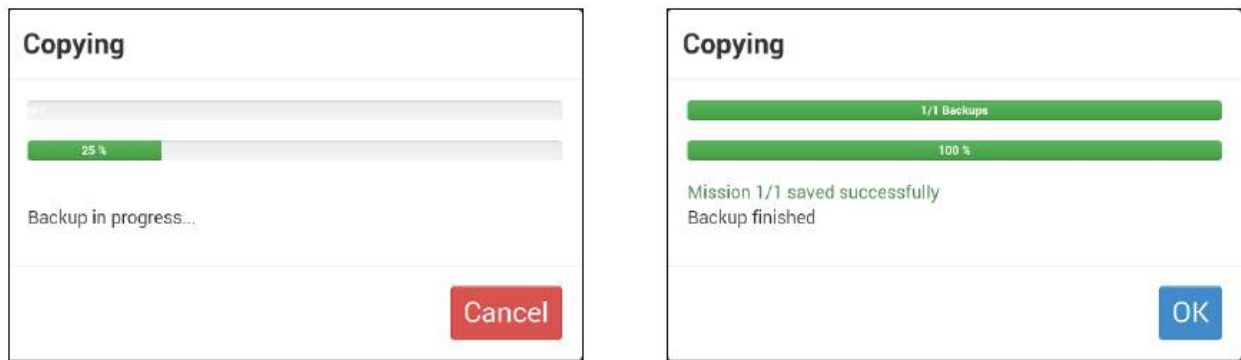


Figure B.14 Images of backup progress windows.

20. Select **Eject external device** and unplug the HD from the MX7.
21. Choose the X in the upper right corner to return to the main screen.
22. Select the X in the upper right corner of the main screen to perform shutdown.
23. When shutdown is complete power off the Power converter unit, tablet and proceed to unplug cables and remove MX7 from the base plate. Carefully put everything in the cases and the collection is complete.

APPENDIX C

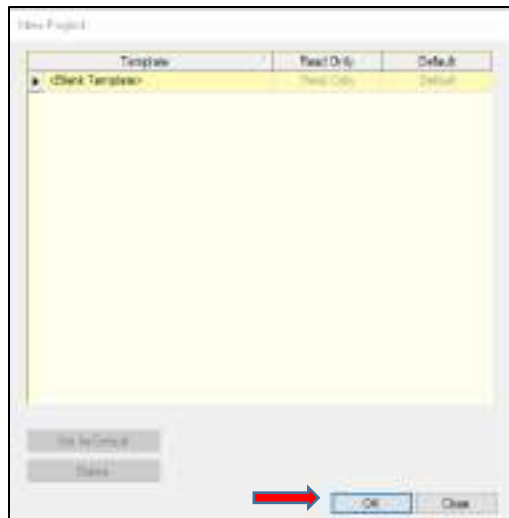
POSPAC WORKFLOW

The following outlines the procedure for use of the POSpac software.

1. Select New Default Project



2. Select OK to use a Blank Template



3. Drag and drop the files from the POS_1/raw folder into the project after the new project is open.

TH22 > NB > TMX7316092702-000060 > POS_1 > raw						Search raw		
Name		Date modified	Type	Size				
	posl_TMX7316092702-000060.000	6/5/2018 8:48 AM	000 File	12,332 KB				
	posl_TMX7316092702-000060.001	6/5/2018 8:52 AM	001 File	12,320 KB				
	posl_TMX7316092702-000060.002	6/5/2018 8:56 AM	002 File	12,311 KB				
	posl_TMX7316092702-000060.003	6/5/2018 9:00 AM	003 File	12,335 KB				
	posl_TMX7316092702-000060.004	6/5/2018 9:04 AM	004 File	12,325 KB				
	posl_TMX7316092702-000060.005	6/5/2018 9:07 AM	005 File	7,387 KB				

4. A project window will open after the files are loaded. Use selections below and choose OK.

Rover Antenna Specification

Rover antenna type is Applanix LV59.




☒ Applanix ☐ Other

Manufacturer: Applanix

Type: LV59



OK Cancel

- Locate the G,N,O base files either from a local ground base or the CORS Network. Once located drag and drop the files into the project.

	Mkt2156M.18g	6/5/2018 7:59 AM	18G File	24 KB
	Mkt2156M.18n	6/5/2018 7:59 AM	18N File	41 KB
	Mkt2156M.18o	6/5/2018 7:59 AM	18O File	7,918 KB

- Choose OK to the Receiver Raw Data Check In.

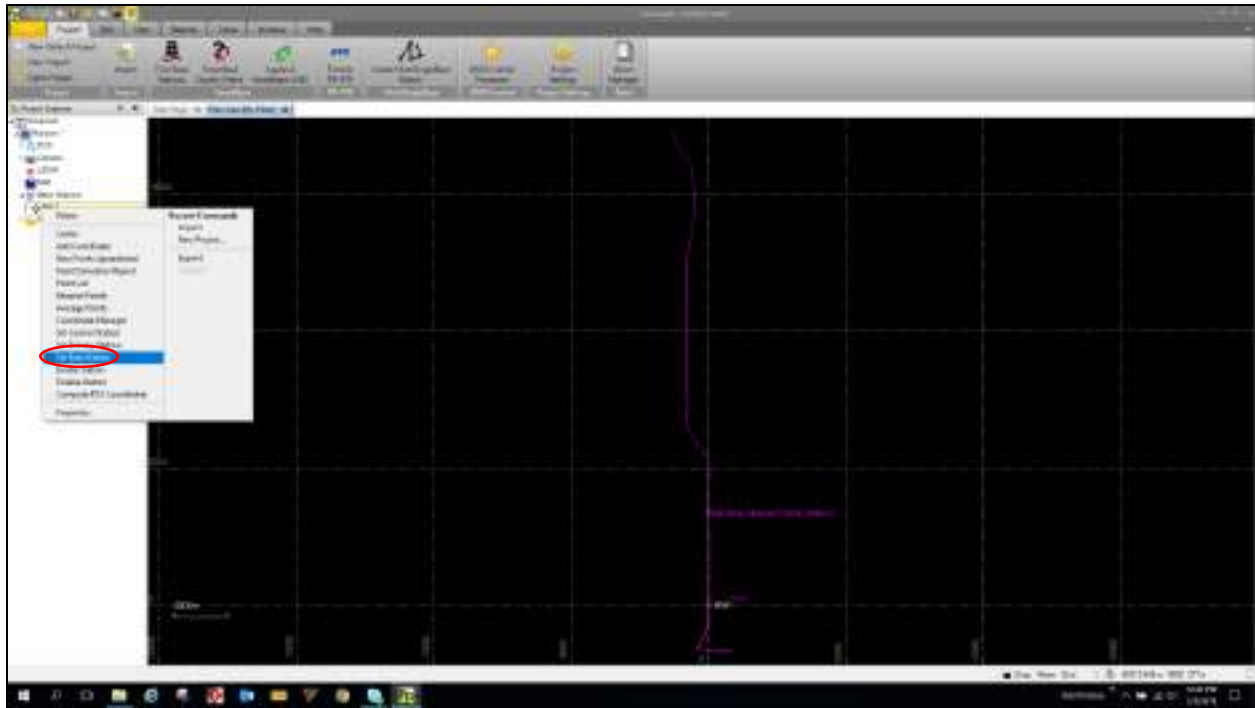
Receiver Raw Data Check In

Import	Point ID	File Name	Start Time	End Time	Duration	Feature Code
	PK2	Mkt2156M.18g	6/5/2018 12:00:00 PM	6/5/2018 12:00:00 PM	00:00:00	
	PK2	Mkt2156M.18n	6/5/2018 1:00:00 PM	6/5/2018 1:00:00 PM	00:00:00	

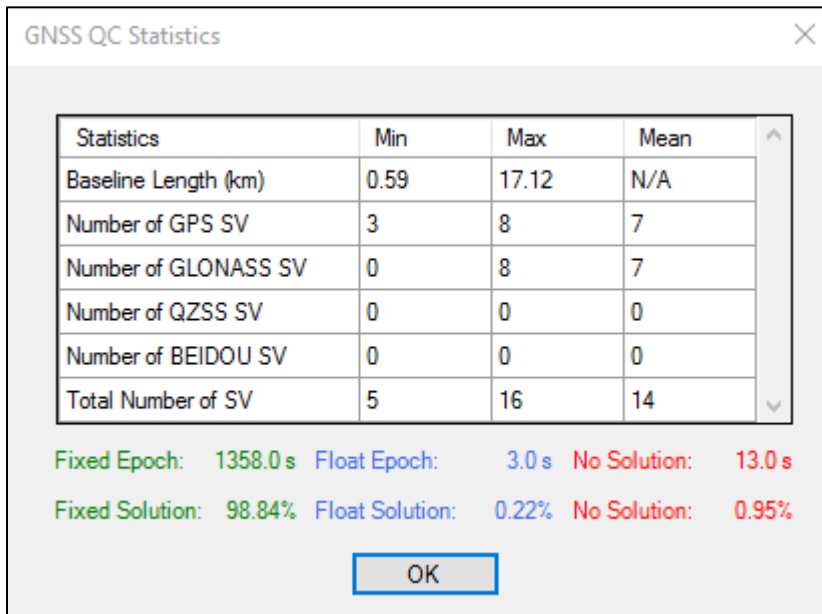
Point: Antenna: Receiver:

OK

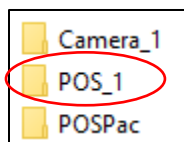
- In the Project Explorer, navigate to Unnamed/Mission 1/Base Stations and right click the specific base station and choose Set Base Station.



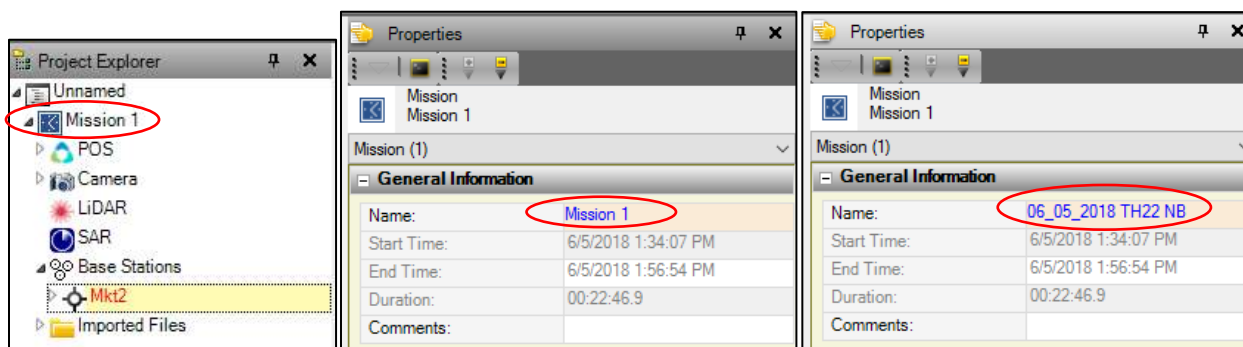
8. Once the Set Base Station process is complete, select OK in the GNSS QC Statistics window.



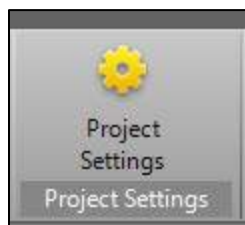
9. Select the Project Select File/Save Project to save the project. Create a new folder in the project folder called POSpac, if one has not already been created, and then name the project with the collection date and route.



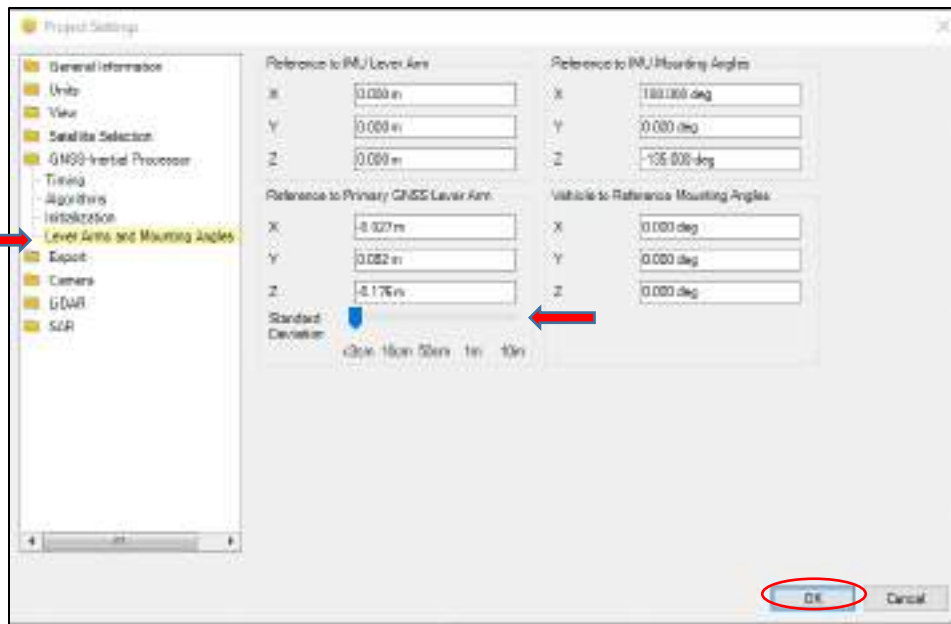
10. After the project is saved the mission will need to be renamed. Double click Mission 1 in the Project Explorer and a properties window will open on the right side of the project. Change the name Mission 1 to the name you used to save the project.



11. Select the Project Settings Icon on the top toolbar.



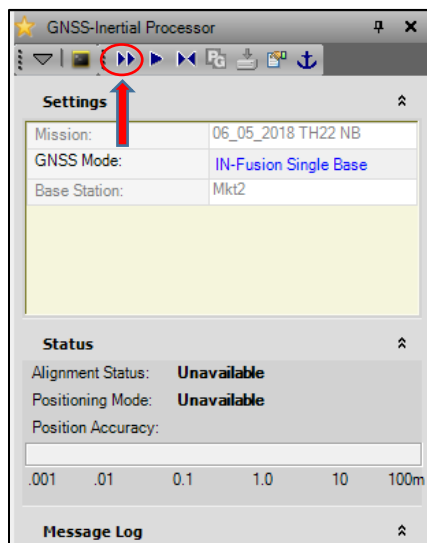
12. The Project Settings window will appear. Navigate to GNSS-Inertial Processor/Lever Arms and Mounting Angles. Slide the Standard Deviation all the way left to <3cm. Choose OK.



13. Select the GNSS-Inertial Processor Icon from the top toolbar



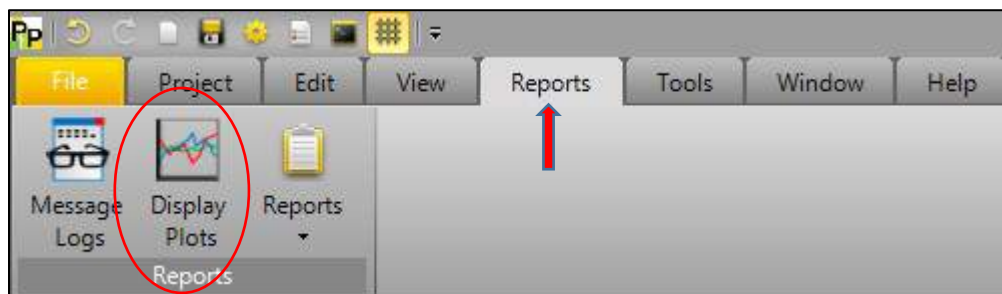
14. The GNSS-Inertial Processor window will appear. Verify the mission name, GNSS Mode, and Base Station. Then select all processing (>>)



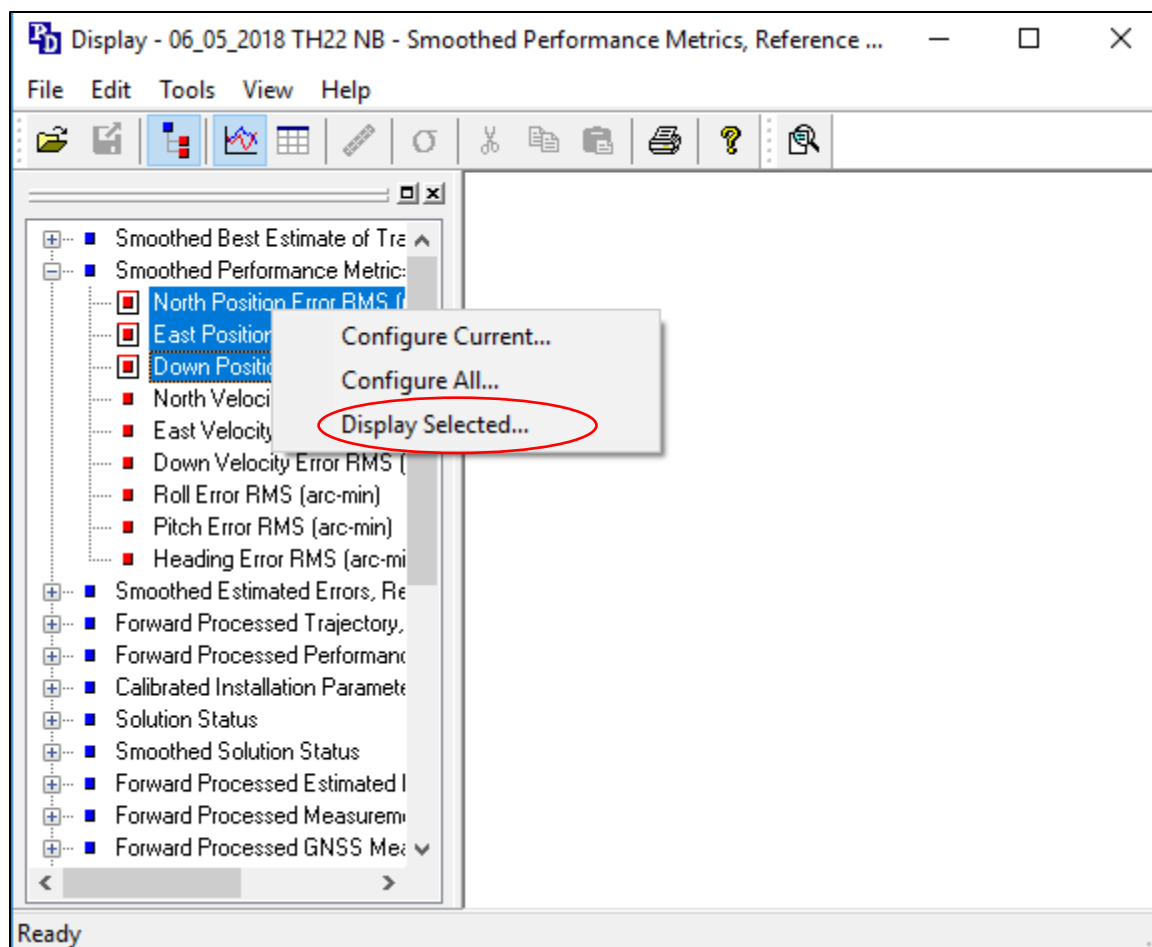
15. There will be a message log showing the process. Once complete choose Close.



16. On the top ribbon choose Reports then Display Plots.



17. In the Display window expand the Smoothed Performance Metrics and highlight North position error, East position error, Down position error. Next, right click in the highlighted area and choose Display Selected.



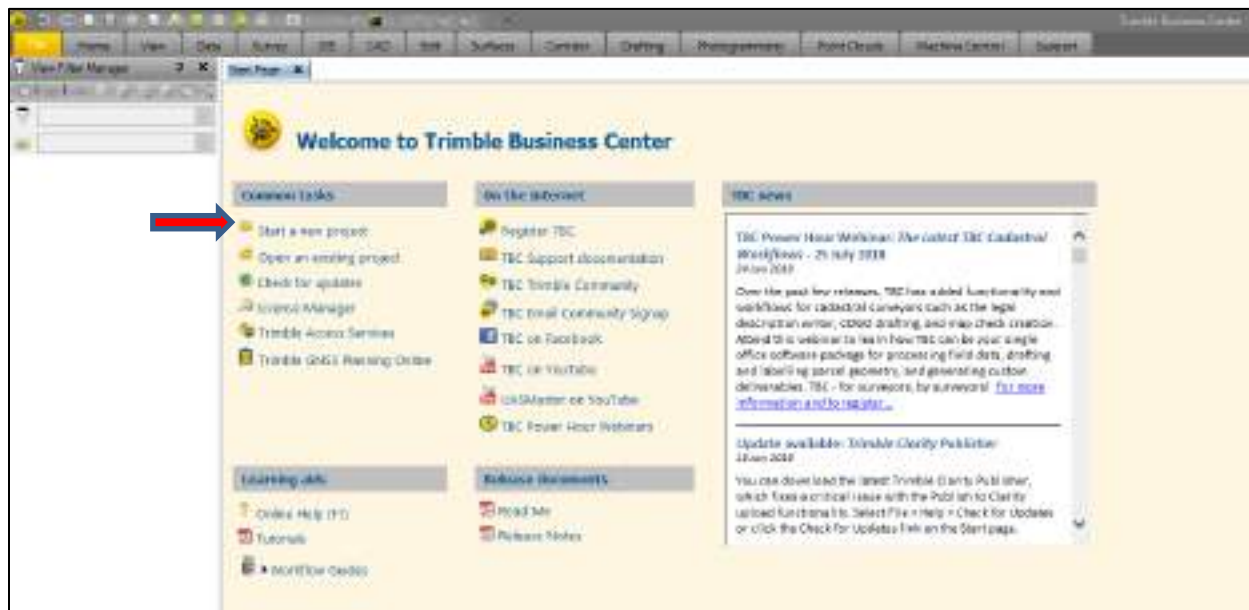
18. A graph displaying the errors will appear. This shows the GNSS errors during the data collection. Close this window and POSPac after completion of the review.

APPENDIX D

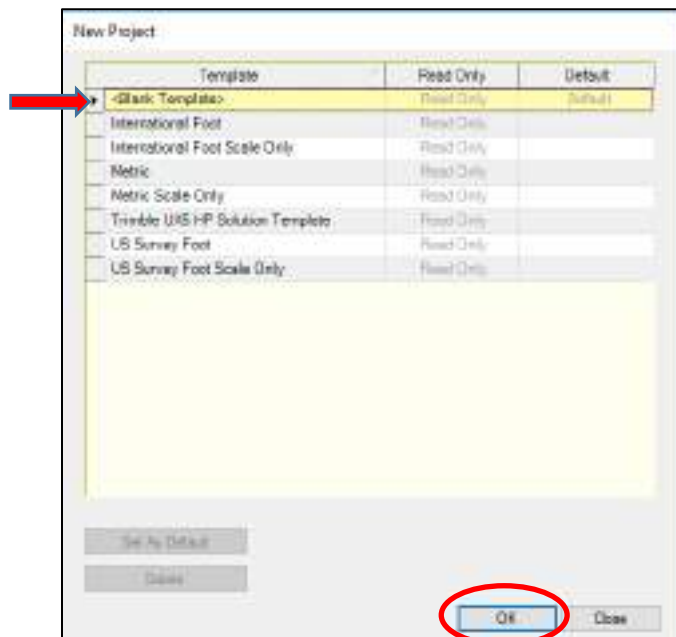
TRIMBLE BUSINESS CENTER PANORAMA AND TRAJECTORY WORKFLOW

The following outlines the procedure for use of the Trimble Business Center software for creation of Trajectory and Panorama *csv files. See Frontier Precisions Webinar for additional details (<https://youtu.be/CorNu07Vj00>).

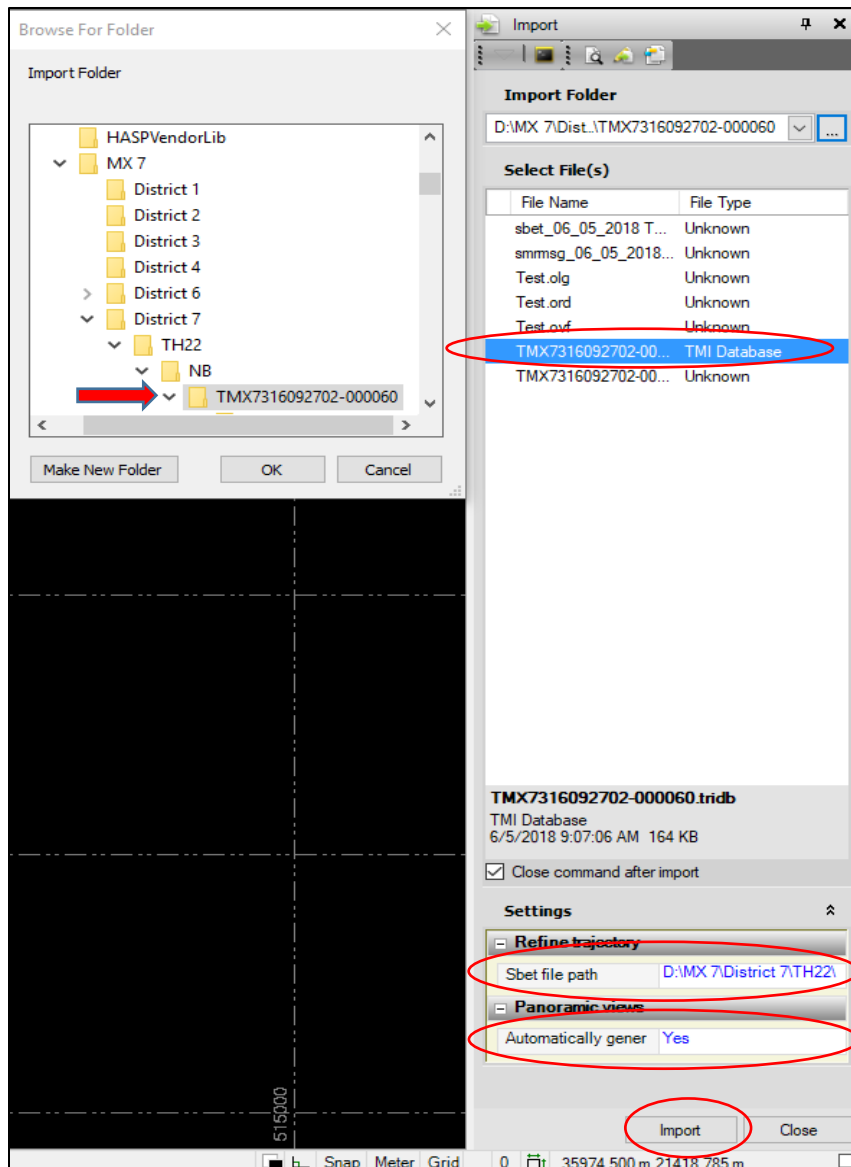
1. Create a New Project.



1.1 Select Blank Template.



1.2 Set the coordinate system to: World wide/UTM 15North WGS84.



1.9 Choose the process View tab and to see a progress bar



1.10 The Process View will display Finished when the import is complete.

APPENDIX E

TRIMBLE MX ASSET MODELER

The following outlines the procedure for use of the Trimble Asset Modeler software for creation of features.

1. Importing Data
 - 1.1 Select Ok in the license manager to access software once verified.
 - 1.2 Choose procedures from bottom left.
 - 1.3 Select the arrow next to Administration to expand choices.
 - 1.4 Select the arrow next to Mobile mapping to expand choices.
 - 1.5 Choose Import run.
2. Importing Panorama and Trajectory *.csv files
 - 2.1 Select the folder to the right of the directory input to create a new folder under the project called TMX. Verify this is the active path in the directory.
 - 2.2 Name the Run by typing it in the Name input.
 - 2.3 Template > choose Equirectangular from the drop down.
 - 2.4 Choose Create Run.
 - 2.5 You will then be prompted to choose the trajectory.csv file. Navigate in the directory and select the trajectory.csv file (stored in the same folder as the panoramas) choose the next arrow.
 - 2.6 You will then be prompted to choose the panorama.csv file. Navigate in the directory and select the panorama.csv file (stored in the same folder as the panoramas).
 - 2.7 Paste photos in the folder path shown, or create a link.ini file in this file path and paste the path to the directory where the photos are located.
 - 2.8 Choose next.
 - 2.9 Fill out metadata (optional).
 - 2.10 Choose finish.
3. Reminder to open the OMR file and change the measure up height to 2.475 (Ford truck) and select save.
 - 3.1 TMX must be shut down and re-opened at this point to accept the new height in the OMR file.
 - 3.2 Repeat steps 1.1 – 1.5.

- 3.3 Choose open run to select the project from the list to reopen.
 - 4. Viewing/Progressing through Mobile Images
 - 4.1 Select the Mobile mapping tab in the center of the screen to open a view.
 - 4.2 Select open view
 - 4.3 Left click on the 2D map away from a photo and the image(s) will appear in the lower half of the screen.
 - 4.4 To close a view move the cursor over the window number and an X will appear.
 - 4.5 Advance through the photos by choosing the blue dots in the photo or holding CTRL and using the mouse roller wheel.
 - 5 Views
 - 5.1 Choose the Preferences icon on the top.
 - 5.2 Choose the MM icon under Extensions.
 - 5.3 This opens a window with options to allow you to change the number of views that open with a single click on the 2D map.
 - 6. Select the active coordinate system displayed at the bottom of the 2D map. Navigate and select the coordinate system you would like to make active.
 - 7. Creating Features
 - 7.1 Choose the + dropdown in the upper left corner of the screen in the navigator to choose New vector dataset. The vector dataset is where the points will be stored.
 - 7.2 Fill out the required inputs for naming the dataset and choose the arrow on the bottom to advance to the next step of the procedure.
 - 7.3 You can import data (i.e., *.csv files) by the drag and drop method into the top left pane explorer.
 - 7.4 Once the data set is created you can right click it to choose the legend editor to change the settings, and set the coordinate system. (for help view online knowledge base, orbit online license activation for website and proof of license)
- OVF file is project specific saved file containing points collected.
- 7.4 Enable viewing of the layer by clicking the puzzle piece next to the layer. The record feature is the circle next to that. Record must be selected to store to the layer.

8. Appending Additional Features
 - 8.1 In any open view choose the open measure window icon to select the procedure to store points, lines, and measurements to the active dataset.
 - 8.2 Choose copy to feature in the measure window to store to the dataset after the measurement has been made in the view window.
9. Export Data as *.kml File
 - 9.1 Right click layer and choose Export dataset.
 - 9.2 Change the file type to KML in the Files of Type dropdown.
 - 9.3 This KML file will be stored by default to the TMX folder you created.
10. Import KML file in Trimble Business Center
 - 10.1 Open Trimble Business Center
 - 10.2 Choose US foot
 - 10.3 Set the MN county coordinate system
 - 10.4 Drag and drop exported KML file to load into Trimble Business Center for review of measurements.

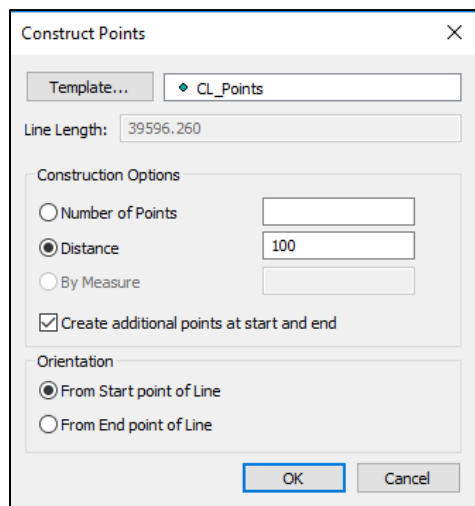
APPENDIX F

ARCGIS LINEAR DISTANCE BETWEEN POINTS WORKFLOW

The following outlines the procedure for calculating the linear distance between the control points (points collected through conventional survey methods) and those generated by the Trimble MX7 for determination of position error.

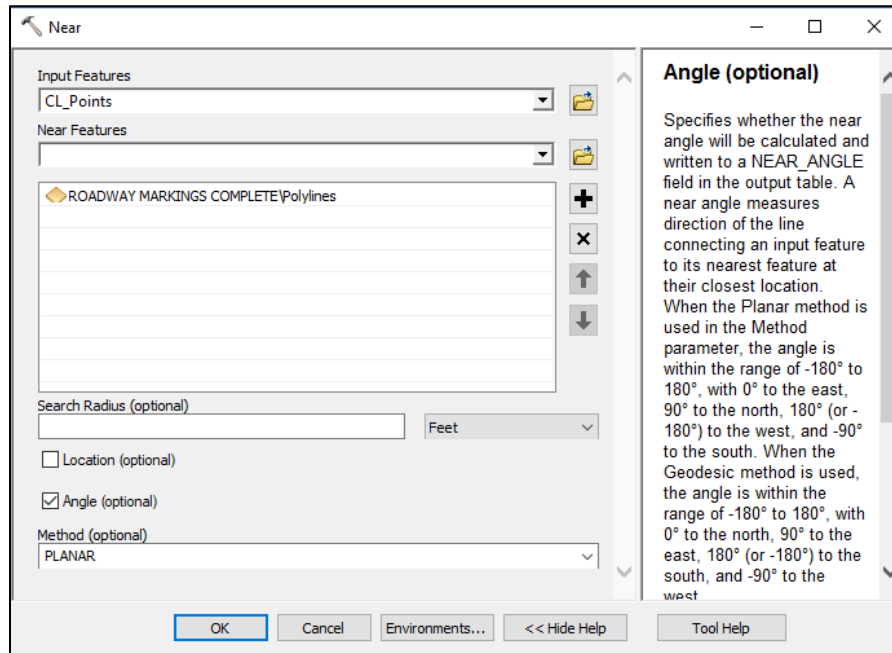
Software Used: This process was performed with ArcGIS Desktop 10.5 and the Spatial Analyst extension. The steps suggested, below, assume a general understanding of ArcGIS Desktop functions and terminology.

1. Isolate Center Line (CL) features from the DGN, export to shapefile ("CL_Measure.shp"). (The in-place alignment generated by conventional survey methods for extraction of DTM coordinates for comparison purposes.)
2. Use the "Define Projection" tool on "CL_Measure" to match County Coordinate System
3. If the CL features contain more than just the CL lines, pair down features to only the centerline using the a length calculation to select the station index lines (typically <10') and delete them from the feature class. Additional cleanup may be necessary to eliminate non-CL features.
4. With remaining CL features only, in edit mode, select all and "Merge" into a single CL feature.
5. Create a new "CL_Points.shp" shapefile to house the array of points along the CL for measuring distance to the MX7 line. Specify the current coordinate system for the Spatial Reference, then add it to the ArcGIS project.
6. Start editing on the "CL_Measure" layer, then select the CL feature.
7. From the Editor menu, select "Construct Points ..."



8. Save your edits and stop editing
9. Sometimes the DGN's CL and the MX7 line do not start or end at the same place. Edit the points to eliminate any that are beyond the ends of the MX7 line.

10. Add Easting and Northing fields to CL_Points, then calculate them using X and Y of the current coordinate system. These coordinates will be helpful for display in other applications.
11. Use the Near tool to then calculate each point's proximity to the MX7 line and check the "Angle" option, which will help to evaluate which side of the line each point falls.



12. Create a field "MX7loc". Selecting those points with a NEAR_ANGLE of negative will isolate all those points on one side of the line. Positive values will return those on the other side. Use this field to create a descriptor to distinguish where the MX7 data was in relation to the CL alignment.

The Near_Angle feature is also used when comparing Trimble MX7 locations to the photo target locations.