Office of Land Management
Photogrammetric Unit

GPS/RTK Accuracy & Procedure Report Concerning Ground Control for Aerial Photography

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Abstract

As the Department moves forward with the various transportation projects, the demand for mapping products has increased drastically in the recent past and will continue to do so into the foreseeable future. This demand has created the need for a quicker turnaround time from the district surveys office for the ground control. With such a demand, the Photogrammetric Unit has seen an increase in errors and blunders in the control point accuracy.

This report has two purposes, the first is to be reactive to this recent error problem and address those concerns. Secondly, to be proactive in dealing with the current work environment by demonstrating the value in doing the job tasks correctly and thoroughly. This will be done by clearly stating expectations regarding field and office procedures when using Real Time Kinematic (RTK), Global Positioning System (GPS) equipment for ground control for aerial photography. In addition, other aspects relating to ground control such as the aerial planning process, targeting procedures and accuracy standards will also be reviewed.

The three improvements that this report should trigger are:

- Improved selection of target, center point and test point locations.
- Review of current field and office procedures and comparison with the latest technologies available to identify opportunities for improvement of Mn/DOT practices.
- Clarify that Mn/DOT standard practice are important and that they must be followed.

This report draws special attention to using the double-stubbing technique and the Multshot program currently available through the Surveys Automation Unit.

Introduction

This report was initially requested by the attendees of two meetings held in July and December of 2003 at Arden Hills, regarding the accuracy of control point coordinates as they relate to ground control for aerial photography. During the preceding 12-18 months, the Photogrammetric Unit and their consultants had experienced a greater frequency of errors and blunders in the photo control coordinates. The majority of these errors occur during the collection process of control point data and test point data.

The group of Metro Survey Office personnel, District Surveyors and Photogrammetric Unit personnel concurred that a review of survey field and office procedures were necessary in order to reduce time and effort spent by all groups tracking down these errors. This report brings to light what has been happening over this time period, and outlines the steps necessary for sound surveying practice.

Included herein, are recommendations for field and office personnel to ensure that information is collected and reviewed in a manner that is consistent with Mn/DOT policy.

Since the conception of this report, many changes have occurred, including changes in the leadership of group personnel and directives about the sharing of public data. These changes have initiated a request that this report be expanded and made available to those outside of the department, as a reference tool for doing this type of work.

A department directive is the new Electronic Data Management System, EDMS that will store, retrieve, sort, reports, delete and organize the data for easier compliance with the Data Practices Act. At this time all electronic data with the exception of CADD files will be stored in EDMS.

Many of the quotes, statistics and definitions were referenced from the Surveying and Mapping Manual (1 July 2000), known as the *manual* and were used liberally throughout the creation of this document. Note: The request forms (2) have changed from those shown in the manual.

Located in Appendix A is a Review of the Photogrammetric Mapping Process which should give the reader an appreciation for the mappers job and the re-work effort needed when field control points are found to be in error.

Located in Appendix G is a list of land cover types and codes used for testing of LiDAR derived digital elevation models. This is the outcome of guidelines on such data published by the American Society for Photogrammetry and Remote Sensing and the National Digital Elevation Program.

Users of this report are invited to submit suggestions for change or improvements or errors to be corrected to the Photogrammetric Engineer, Photogrammetric Unit of the Office of Land Management.

Planning an Aerial Photography Project

This section was added to the report to help the Department's consulting partners understand the process that Mn/DOT uses to get a mapping project ready for aerial photography. People not familiar with planning aerial photography projects should read Appendix B.

Targeting a Project

The information in this section is for background purposes for those new to the setting of targets for photogrammetric mapping control prior to aerial photography. The section includes tips on what to do and what not to do, and will provide insight to all users regardless of the experience level. See Appendix C for details.

Center Point Data & Test Point Data

Center point data (CPRO) and test point data (TPRO) serve two distinct purposes. The center point data has horizontal and vertical coordinates and is used to verify, and adjust if necessary, the stereo model to statistically even out the model. The test point data is used only when the project has been completely compiled and is used as an independent data set to test the accuracy of the completed model.

The selection of the physical location of CPRO and TPRO points and the accuracy with which they are measured are where the majority of the problems have occurred with regards to errors and blunders and will be the focus of the report. The equipment and processes used for collecting this data has not been uniform, due to many circumstances. The equipment part of this scenario will be discussed later. The process however needs to be addressed in order to reverse the current trend. The first place to start is the appropriate and inappropriate locations for the CPRO and TPRO shots. The following pictures, Figures 1 through 3 are examples of questionable locations and should not be used as a general practice. The emphasis of the photo is on the location of the shot selection, not whether the staff is completely outfitted correctly or if it is plumb.

Figure 1 shows a gutter line shot, this is not a good location because one foot or more separate the break line features for the top of curb and gutter line. This is done in order to insure that the break lines do not cross at any point. The stereo operator has a limited space in order to create the two break lines while looking at a magnified image. The use of the location illustrated in Figure 1 for CPRO or TPRO shots would tend to give erroneous results given what is known about the makeup of that feature break line.

Figure 1
This is an example of what not to use.

Again referring to Figure 1, a CPRO or TPRO shot, four or five feet from the back of curb and on the grass will work well in this situation because it will accomplish the goal of being in an area that is representative of the ground and will not interfere with the next adjacent feature. The other features that are present in the photo that need to be considered are light post, stop sign and a landscape garden. There is a slight conflict here because of the contrast issue, but it is a question of balance and priority of the CPRO and/or TPRO location.

By keeping the CPRO and/or TPRO shot location away from other elevation features there should be no confusion as to what the intent is. Remember, in the environment of the electronic map, the planimetric feature symbols are plotted oversized, so give every feature enough space to avoid confusion.

Figure 2
This is an example of what not to use.

The center of a paved road, such as shown in Figure 2, tends to be difficult for the stereo operator to see vertically because contrast is needed in order to form a good stereo image of the vertical component. A surface of a solid color with little visual relief tends to be difficult to read over large distances, so unmarked parking lots and freshly paved roads would fall into that category. Once the road has been striped, the contrast is greatly increased and would then become an adequate candidate for a CPRO or TPRO shot.

Once a parking lot or road has been weathered by time, the contrast between the surfaces and other features such as utility manholes becomes more distinct and therefore these other features make good points to focus on. This is especially true when looking for image points to be used as control for existing photography. In this case the stereo operator can pre-select the image points for the surveyor prior to going out in the field.

Figure 3
This is an example of what not to use.

Figure 3 represents a rural road and ditch section. Keep the following in mind; if the flight was done in the spring, the grass would tend to be matted and the shot in the bottom of the ditch will be acceptable. However if the aerial photography were done in the fall, one would have to inspect the photograph in this area and check to see if the ditch had been mowed. Another item to keep in mind is when the ditch has uniform slopes and is 3:1 or steeper, look to other areas outside of the ditch section for a more appropriate location for a CPRO or TPRO shot.

The 3:1 slopes and other steep terrain tends to be another difficult location due to the fact that in certain flight situations the ditch will be casting shadows. Again making it difficult for the stereo plotter operator to read the ground. Older roads with short and steep ditch sections should be avoided while newer roads with flatter and longer continuous slope sides are generally fine for photogrammetric purposes. A large number of ditch shots for TPRO's could tend to skew the statistics toward the larger end of the error spectrum. Ditches should not be used for LiDAR test data.

Figures 4 through 7 are examples of locations that should be considered for CPRO and/or TPRO shots.

Figure 4

The fog line in Figure 4, offers an area that works well because it is away from the curb and offers a contrast with the pavement. Another acceptable area in this photograph would be half way between the back of curb and the fence line because the grass is short. If the grass were higher, like that behind the fence then the location for the CPRO or TPRO would not be good.

In some areas the surveyor must choose to select the least objectionable location versus the best location. This is easier for someone having field experience.

These are not hard concepts to conquer, but it is often surprising at what arrives back in the office when other options appear much better.

Figure 5

In the rural area, row furrows can present problems, Figure 5 shows furrows that do not present much of an elevation difference between neighboring rows. These particular row furrows have been softened due to an unusual amount of rain. A shot just about anywhere would represent the ground, however if the elevation difference between the top and bottom of the rows were greater, the surveyor would need to find a shot location that represents an average of the tops and bottoms of the rows. The point here is that the condition of the ground may have changed since the photography was taken. A quick look at the photography should give the surveyor a clue as to what the condition actually was. Again this may seem like a minor point but it tends to show up in the level of experience of the surveyor out in the field.

This situation is not as critical to the creation of the DTM as the other examples but it can often be used as a gauge to get a feel for the development of the inexperienced crew chiefs. A probing question about what they felt the terrain looked like and where they decided to take the shots, could be revealing in either case.

Figure 6

Field entrances, as shown in Figure 6, are good locations for CPRO and TPRO shots because the area is rarely occupied or obscured at that location, additionally the few feet surrounding the shot are usually flat or uniform, contrast is not far away in the form of elevation (ditch) and color or shade (grass). It is not always known in advance but there have been times when the engineer or designer wants to know about the amount of cover over a drainage pipe and this way the information is field verified.

Another time saver would be to combine CPRO shots with centerline road profiles on cross streets when a strip of photography includes the cross street. The field surveyor will have to adjust the interval between shots to the minimum distance interval required which would be in the neighborhood of fifty foot spacing.

Figure 7

The intersection of two sidewalks, Figure 7, is one of the best examples of the ideal CPRO and TPRO shot location. Contrast is evident in color or shade and the surface is uniform as long as there is not a retaining wall or other vertical structure adjoining the sidewalk. A few simple guidelines together with some experience will go a long way in knowing what situations represent CPRO and TPRO locations that work for the photogrammetrist.

Multshot Program

When RTK is used to collect the CPRO and TPRO data, many times there is no report as to whether or not the data was collected using a single or double stubbed technique. This report is usually available somewhere in the software but often is not produced by office personnel. With RTK, all CPRO and TPRO data sets must be double stubbed. The statistical reliability in catching errors and blunders using a double stubbed procedure is too great to ignore. Currently, single observation CPRO and TPRO data are by far the largest source of errors that are discovered by the Photogrammetric Unit editors. For the most part, consultants do not receive TPRO data but they do receive CPRO data and a few errors have been detected.

There exists a Multi-Shot routine that is available which runs independent from the data collection device and allows the person collecting the data or the office supervisor to review the work and check it for accuracy, before submitting it to the Photogrammetric Unit. A sample of this is shown as Figure 8. This routine is a product of the Surveys Research and Support Group in Central Office and is on the OLM server at:

\\Dot-lm-gw\DATA\SURVEYS\MnMultShot\MnMultShotInstal160.exe.

The Photogrammetric Unit has <u>not</u> required the submittal of this report, but it would be in everyone's interest to use this report as a check before submitting the CPRO and TPRO files to Central Office. This routine is not limited to just the CPRO and TPRO positions but could also be used for the reporting of the target position. Currently many district offices are using this report for double stubs on targets and a few are using it for the CPRO and TPRO shots. The Photogrammetric Unit would encourage that all districts to send the Mult-shot report, in any form, to the Photogrammetric Engineer for inclusion into the Map Accuracy Report

Nothing but positive outcomes should occur when using a report like this, it will instill confidence in the person collecting the data and will support the integrity of the work from those outside of the surveyor's office against those challenging the work. The Multi-shot Report is listed in the list of documents to be retained as a Photo Control Report and is to be included into EDMS.

```
        Photo Control Multi-Shot Report     (English)    03/31/2004       Page 1
T.H.:I-90   S.P.:3280-08   Desc:
Horizontal Datum:NAD83(96) Jackson County         Vertical Datum:NAVD88
       Files:Photo Test.cdf
(Photo Control Maximum Splits:  Horizontal = 0.25ft  Vertical = 0.20ft)


Point Num        Description            X (f)        Y (f)     Elev (f)
---------  ------------------------  -----------  -----------  --------
4102        #7726                     496804.063   110142.670   828.013
4102        #7726                     496804.026   110142.886   828.073
           Mean Coordinate            496804.044   110142.778   828.043
Max Split  (Horiz Distance = 0.219)        0.037        0.216     0.060

4104        #7726                     496966.646   110147.426   829.809
4104        #7726                     496966.638   110147.459   829.846
           Mean Coordinate            496966.642   110147.442   829.828
Max Split  (Horiz Distance = 0.034)        0.008        0.033     0.037

4117        PIPE 1/2 INCH             497016.114   110345.559   837.579
4117        PIPE 1/2 INCH             497016.222   110345.481   837.726
           Mean Coordinate            497016.168   110345.520   837.652
Max Split  (Horiz Distance = 0.133)        0.108        0.078     0.147

4122        #7726                     496657.253   110298.337   827.964
4122        #7726                     496657.328   110298.301   828.061
           Mean Coordinate            496657.290   110298.319   828.012
Max Split  (Horiz Distance = 0.083)        0.075        0.036     0.097

4140        #7726                     496578.103   110376.274   827.668
4140        #7726                     496578.183   110376.235   827.588
           Mean Coordinate            496578.143   110376.254   827.628
Max Split  (Horiz Distance = 0.089)        0.080        0.039     0.080

4214        #9053                     496748.189   110030.937   825.567
4214        #9053                     496748.199   110030.804   825.438
           Mean Coordinate            496748.194   110030.870   825.502
Max Split  (Horiz Distance = 0.133)        0.010        0.133     0.129

4306        #14376                    495691.658   110233.190   818.431
4306        #14376                    495691.553   110233.169   818.405
           Mean Coordinate            495691.606   110233.180   818.418
Max Split  (Horiz Distance = 0.107)        0.105        0.021     0.026

4317        #14376                    495811.128   110476.824   826.600
4317        #14376                    495811.033   110476.789   826.584
           Mean Coordinate            495811.080   110476.806   826.592
Max Split  (Horiz Distance = 0.101)        0.095        0.035     0.016

4477        PIPE 1/2 INCH             496689.701   117187.673   848.085
4477        PIPE 1/2 INCH             496689.558   117187.741   848.284
           Mean Coordinate            496689.630   117187.707   848.184
Max Split  (Horiz Distance = 0.158)        0.143        0.068     0.199

Horizontal Splits (9 points):    Mean = 0.118    Std. Deviation = 0.135
Vertical   Splits (9 points):    Mean = 0.088    Std. Deviation = 0.112
(Splits Over Photo Control Maximums:    Horizontal = 0    Vertical = 0)
```

Figure 8

Double stubbed data sets are going to cause time issues and procedural problems with the survey crews, in that the CPRO and TRPO collection process could possibly take twice as long as the single shot process. The double stubbing that is being done on successive days and staggered times to achieve a shift in the satellite configuration, will present additional problems in trying to keep track of the first set of points without resorting to some inefficient method of navigation that adds critical time or other use of resources. The upside is that it is precisely the new satellite constellation that insures good geometry for a successful solution. The time gains or losses will be measurable when one thinks of the number of error-checking return trips that may be necessary if the observations were only to be made once.

Time and money spent to do a project correctly should not be the issue but often is. The argument is that the real savings is in doing the job right the first time. The benefits of using a proper double stubbing technique greatly out weighs the time loss if it is done in one organized and efficient effort.

One also needs to consider that conditions are not optimal every time one performs a GPS survey and there appear to be non-optimal times during each day. A closer look at Figures 9 thru 12 (see CORS v. Mobile Base Station Section) will clearly show this phenomenon. The surveyor should take note that this is the classic case of the percentages being in ones favor when the job is done right the first time. Relying on a single stub, one time effort is inviting the need to return to the site to check previous work. Please note that the scatter of shots will range in the 0.5-foot area as a maximum with majority lying in the 0.1-foot range.

From strictly a survey technical point of view, a shifted constellation over a few hours or even the next day will raise the confidence level considerably. Another consideration should be that the meaning of two independent readings gives the user and office supervisor a chance to check the integrity of the data before it leaves the office.

Furthermore, knowledge of the fundamental behavior of RTK, VRS and total station systems must drive the decision as to which tools and methods are acceptable in accomplishing the task at hand. This must be a conscious and conscientious effort.

LiDAR Test Points

The increased use in LiDAR technology for hydraulic studies and preliminary design data now requires the district surveys office to collect test data to ensure the accuracy of this product. There are a few differences that must be observed when collecting data for LiDAR versus collecting data for photogrammetric purposes, but as a general rule the same care with survey procedures should apply.

The major difference is in the data collected and categorized using land cover types. The codes used to describe the land cover types have been adopted from two sources, the

National Digital Elevation Program (NDEP) and the American Society for Photogrammetry and Remote Sensing (ASPRS), Guidelines for Vertical Accuracy Reporting for LiDAR Data and can be found in Appendix G.

Accuracy Standards

The Minnesota Department of Transportation has adopted the National Standard for Spatial Data Accuracy (NSSDA) as the working standard for their mapping products. The specifics about these standards, the computing and reporting of the accuracy statement can be found in Appendix H or in the Surveying and Mapping Manual, Sections 4-8.01 through 4-8.05.

GPS v. Traditional Survey Methods

In many areas of the state, GPS has become the tool of choice for the surveying community. Rightfully so, if the field and office procedures are followed carefully, the advantages simply outweigh the drawbacks. The time saving alone justifies its use and for most of us within the profession, this is a major consideration.

Technology in the survey profession has grown exponentially and parallels that of many other professions. Tools that require fine tuned skills have been outmoded. It is the loss of the skill set that is most concerning and fear that this has lead to a dependency on technology. Technology can be a good thing, but dependency on technology has its drawbacks. A powerful tool in the hands of an unskilled worker can cripple an organization with doubt and mistrust. For the Survey Unit to remain a source of confidence and trust, the continuation of proper training should keep the unit on course. Since the survey leadership at every level within Mn/DOT spans both the GPS and traditional eras, the supervisor is able to make decisions as to which of these methods work best for each particular project or a particular area within a project.

One advantage of the traditional method is that there are certain steps within a given procedure that call for mathematical checks that verify or dismiss the results and therefore boost confidence in the work. The best analogy is that when survey equipment was rudimentary, one needed good office and field procedures in order for each group to be confident in their work. Because technology has simplified the physical and mental exercises relating to surveying tasks and in many cases reduced it to a simple value often without well-recognized error checking procedures, one is left dependant on that value. This relates to both field and office tasks where technology gains arrived long before GPS or CADD was employed. The changes that have occurred in survey procedures have gotten to the point were simple checking have been put off or simply forgotten.

There needs to be a return to the tried and true procedures of checking the work before leaving the site or office.

With GPS, the procedures guided by the software, preparing the results and doing the calculations out of sight, we have become fixated on the software telling us the results are good and not searching for and verifying the results. In most cases this requires extra work, yet this lies at the heart of what surveying procedures are all about, checking and verifying results. Many within the surveying community do not know exactly what is happening within the software, that is to say we have not followed the exact path of the process of each calculation or conversion or reduction. Some say that it is not necessary that one know exactly what is happening behind the scenes as long as the result is correct.

This being said, we have all been in a situation where someone on the crew or in the office did not follow the proper procedure of checking their work and know the frustration that this has caused once an error has been found. The answer is, we need to have our work checked by human sources and this must be as fool proof as possible to catch any and all errors before we pass our product on. This checking is the responsibility of both the field crew and the office supervisor and each must be diligent in their task in order to safeguard against losing the confidence that has taken years to generate.

Static v. Kinematic

The advantages between doing a static versus kinematic survey are as distinct as those between doing a GPS survey versus a traditional survey. It is generally considered that a static survey is for control or targeting purposes while RTK is the ideal tool for collecting CPRO and/or TPRO data. Consider the setup and breakdown time alone, as this would be too great for practical purposes.

The advantage of a static survey for targeting control is in the certainty achieved when following the post processing procedures. Knowing how one is arriving at the answer is comforting and satisfying in that this procedure gives confidence in the process as well as the results. The post processing procedure also allows the user to enter a variety of key pieces of information and although this may be cited as a source of error it is also a way to properly account for the factors that create or introduce error.

CORS v. Mobile Base Station

It will only be a matter of time before the Continuing Operating Reference Station (CORS) will dominate the GPS operational landscape. CORS is in its infancy and the problems associated with it in order to make it operational under all (make that most) conditions have not all been solved. But until that happens there are a number of things that the user should keep in mind. There is no perfect system, understanding of the flaws or shortcomings should aid the field surveyor in what is appropriate when using the system. There are certain aspects of the CORS that we should be aware of and this includes what happens over a period of time and how that relates to coordinates we use.

Figures 9 thru 12, are graphs of logged data using a standard base station and rover for stations *SEITZ* and *KAPPLER* and using the virtual reference system for station *BOHLKE,* each taken at one minute intervals. Two different tests were performed, one being the Continuous Point option (1 epoch) interval for a 7 hour period and the other being a Measure Topo option (3 epoch) for almost a 5 hour period. Solid red and green lines depict the published elevations and averages, whereas the individual data points represent each shot. The equipment used for this example was a Trimble® model 5800 receivers and 2-meter bipods with a standard cell phone on Verizon® service connect to the Central Office modem.

The purpose of graphing this data is to demonstrate to the user the amount of fluctuation that occurs during the day and that a user is likely to encounter times when the actual elevation or coordinates differ from the published. One assumption that can be made from this test is that the geoid model being used is not modeling the correct elevation. While this may be true, a larger testing area would be required in order prove that theory. In actuality, the distance separating stations *SEITZ* and *KAPPLER* is so short that it seems unlikely that the geoid model is the source of this error. All three stations were leveled through during the same project, see Appendix I, so this would likely rule out any differences between separate level runs. All monuments were reported in good shape during the testing sessions.

The situation as graphed here is happening independent of being attached by a cell phone to a CORS tower or by a radio link to a mobile base station. The difference between the published and this fluctuated elevation is not being taken into consideration and adjusted for and because it is happening on both ends (rover and base), there are two potential sources of unaccounted error. Now a person may believe that these errors are compensating and so has reason to ignore them. This is the case here where the source of error is directly related to a single benchmark calculation and the difference should be transferred directly to the receiver. All sources of errors, once identified should be accounted for. Can the surveyor identify this error at the time he/she is collecting data or account for it later?

Figures 9 and 11 refer to station *KAPPLER* whose published elevation is 914.398 feet and the averages for 1 epoch collection is 914.343 feet and for 3 epoch collection is 914.349 feet. Figures 10 and 12 refer to station *BOHLKE* whose published elevation is 917.472 feet and the averages for 1 epoch collection is 917.333 feet and for 3 epoch collection is 917.379 feet. Right away it is evident from that a greater epoch collection rate is superior to a single epoch rate. The second noticeable outcome of this experiment is superior accuracy performance of the standard base and rover to the virtual reference system, granted the comparison is only 0.05 feet and 0.12 feet respectively.

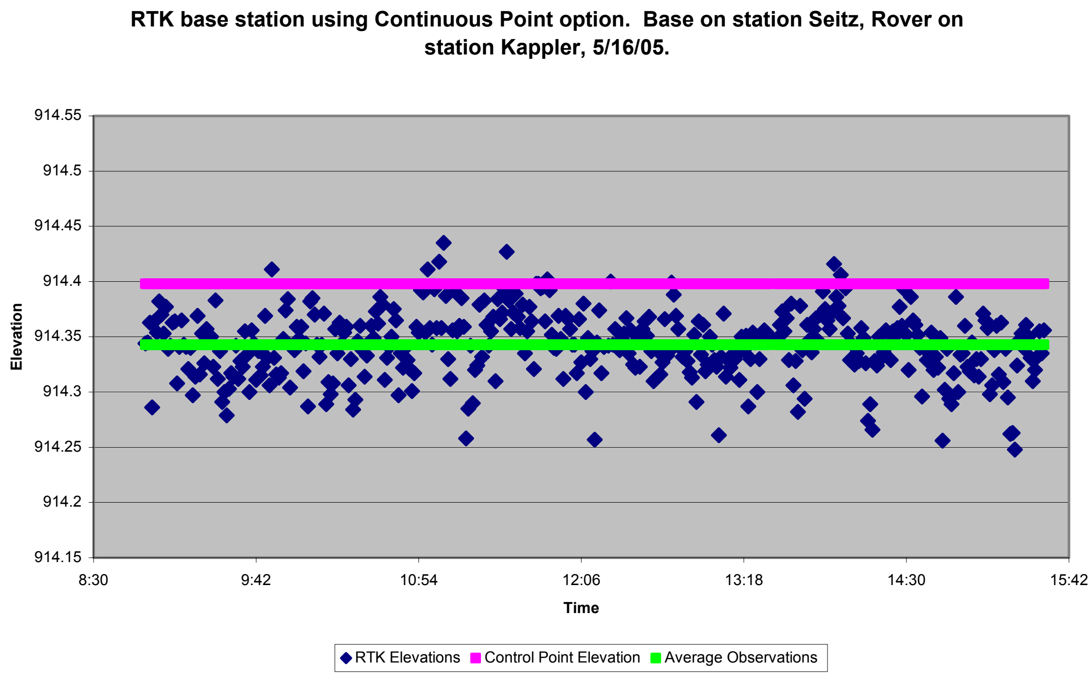

Figure 9

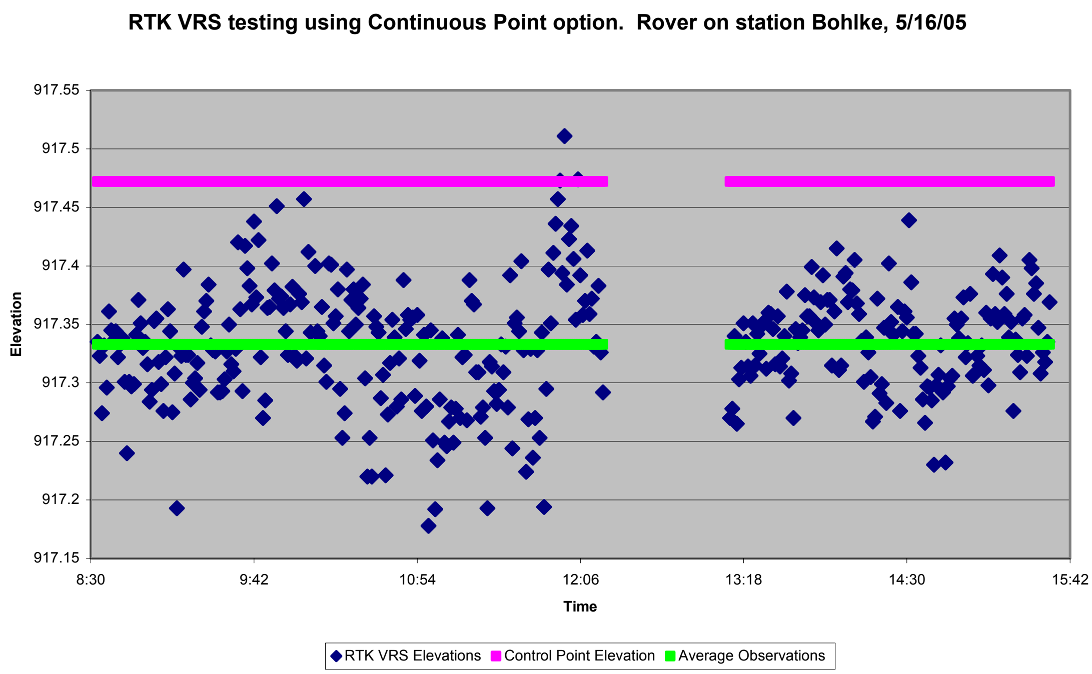

Figure 10

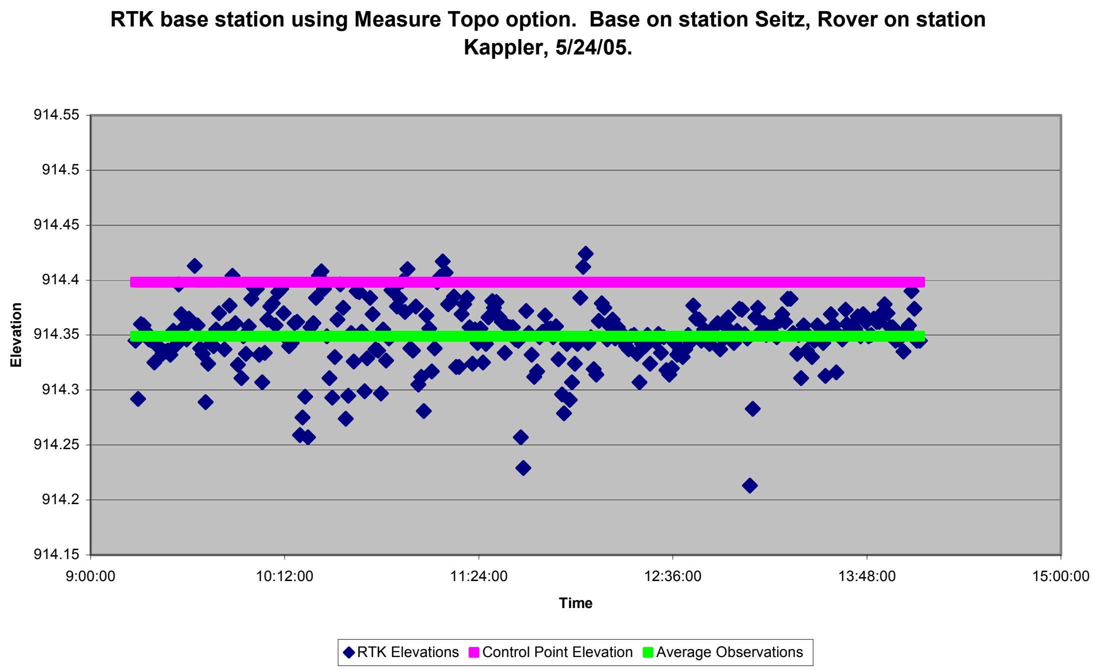

Figure 11

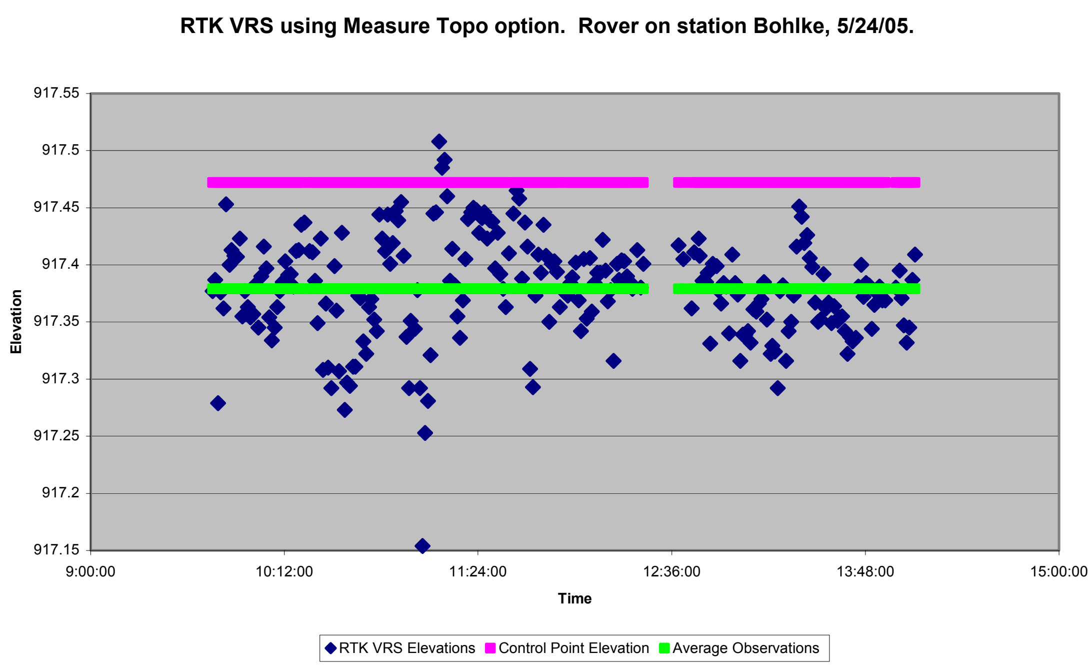

Figure 12

On another source of error, there is an interesting occurrence with regards to both the Mobile Base Stations and the CORS system and that is the effects of weather on the troposphere and how GPS manufactures do not have a way of compensating for this effect in the carrier phase for kinematic surveys. Dixon Hoyle, the NGS Advisor to Minnesota, states that he has discovered variations of as much as six inches in many of the CORS published elevations and he suspects that weather phenomenon may be the cause of this. The most interesting thing is that when adverse weather is local, the surveyor usually has enough sense to shut down the operation. Because of the CORS spacing and the unknown of exactly which station the baselines are being computed from, and that it is a likelihood that the station is beyond the horizon, the surveyor will be unaware that a weather occurrence is taking place.

There is a great possibility that Mn/DOT surveyors will be connecting to the CORS system with greater frequency in the future and we will no doubt see efficiencies rise. We know that the occasional anomaly will happen that we can't account for but we can ensure greater confidence in our work by using common sense and proven procedures. The use of special tools such as the multi-shot tool for all double stubbed occupations, beginning and ending each session with a vertical check and using sound judgment in the location of CPRO's and TPRO's is one of those procedures.

Conclusion

When a project starts to take shape and the decision is made that mapping needs to be ordered, the diagram of the photo limits is the foundation for the targeting scheme. The thoughtful layout will go a long way in helping all other areas insure a quality product. Each project is unique in its topography and many offer simple solutions for the office and field crews, others pose nothing but problems. Either way, it is the field crew that will need to make a decision as to the appropriate location of each and every target. Targeting is critical when setting up each photogrammetric model and working through the aerotriangulation process. While the Photogrammetric Unit does provide a coordinate position for each target, it is the decision about its placement that is left to the field crew.

By choosing the best available location for CPRO and TPRO shots, the likelihood of there being confusion or misinterpretation greatly diminishes. This helps create a more uniform and uninterrupted workflow. Knowing how the stereo plotter operator plots the ground features and break lines will help the field surveyor in the selection process for the proper CPRO and TPRO shots.

Real Time Kinematic, when conditions dictate, is the strongest new tool the surveyor has besides the brain. As the tool of choice for most of Mn/DOT's District Surveying Units, it is our responsibility to fully understand its capabilities and limitations. To that end, using the procedures that have been described herein will go a long way in boosting the surveyor's confidence in the work he submits.

In the future the Photogrammetric Unit will be looking at a number of items that should shed additional light on the current survey acquisition process. These include: the testing of a targeting layout scheme that includes wing pairs at a reduced interval in an attempt to further reduce the frequency of return trips to the field; comparing CORS data over a longer period of time and a comparison of the results from the aerotriangulation process using three different field procedures. The procedural updates or other testing results will be published in the next version of this document or the update to the manual.

A special thanks to Dan Wik for the time and effort put towards collecting the data shown on Figures 9 thru 12.

Appendix A

Review of the Photogrammetric Mapping Process

For the purpose of this section, lets assume the completion of the aerial photography, the field survey work, the creation of the files containing the coordinates for targets, center point data and test point data. All the activities and associated data have been processed and delivered to the Photogrammetric Unit along with a *Request for Photogrammetric Mapping,* see Appndix E, to begin the mapping process. The mapping process is being highlighted here to give the reader a sense of the time and effort required to put the project together with each stereo model. See Appendix H for definitions and for an expanded version of this process, see the Surveying and Mapping Manual, Sections 4-5.01 through 4-5.08.

<u>FIRST STAGE - AEROTRIANGULATION</u>

The first stage in the mapping process is aerotriangulation (AT), where the determination of X, Y, and Z ground coordinates are based on measurements from photographs. Mn/DOT uses a semi-analytical procedure to provide a means in which to utilize a reduced number of field survey points (either targets or image points) to analytically generate a sufficient number of photo control points to map the project. The choice of a semi-analytical procedure was chosen years ago when it was cost prohibitive to do the field work for conventional control, also the analytical method allows one to bridge areas that are inaccessible.

The AT is accomplished with state-of-the-art bridging techniques and the RMSE should have an accuracy that falls within the appropriate standard. If the RMSE does not meet the standard, an investigation of the AT procedure and field survey information is indicated.

<u>TASK 1 - PUGGING</u>

Pugging is the first task in the aerotriangulation stage, which includes marking the artificial control points or passpoints on the diapositives. A 70-micron drill is used to form a hole in the emulsion of the diapositive, but not through the film base. By pugging three passpoints down the vertical center of each photo, a pair of overlapping photos will have six passpoints that will be used as control to set up the steromodels. A monocomparator (XY coordinates) or a stereocomparator (XYZ coordinates) are used to generate relative coordinates. The ground and photo control points are used to set up the stereomodel on the stereoplotter. Just like in a boundary survey, the passpoints are best used when they fall inside the mapping limits set by the targeting layout. If passpoints fall outside of the targeting network they will be based on an extrapolation. For this reason it is important that the targets used for photo control be placed such that they encompass the ideal pug point location. Pugging is a time consuming endeavor due to the exactness required for the drilling operation. This task time is reduced somewhat with the new soft copy AT systems of which we have just purchased.

TASK 2 – CONTROL POINT ADJUSTMENT

Computer processing is the next task and this involves inputting the relative coordinates, field coordinates, camera calibration information and exposure coordinates into any one of many programs that are commercially available. Next, the sequential model is assembled in which successive stereo pairs are processed using a routine involving a least squares adjustment of collinear equations. Strip formation is the joining of stereomodels with a three-dimensional transformation where a series of equations link successive models by common pass points. Then each strip undergoes a polynomial adjustment, which produces preliminary ground coordinates for all control points. The simultaneous bundle adjustment is done to complete the aerotriangulation, where a report will include the residual error introduced for each point and the final root mean square error (RMSE) is calculated.

SECOND STAGE - COMPILATION

The second stage is map compilation. This stage involves digital data extraction that assigns a feature code to a coordinate triplet. Physical features such as roads, buildings, trees, etc., are plotted digitally for planimetric maps and break lines together with spot elevations for the creation of digital terrain models (DTM's).

TASK 1 – PLANIMETRIC FEATURES

In order for Planimetric features to be plotted, they must be visible and identifiable on the image through the stereoplotter. For a true horizontal position, the reference mark within the stereoplotter must be at its true elevation.

TASK 2 – DIGITAL TERAIN MODEL

A DTM is essentially using a database to store ground points and creating data strings which would be similar in principle to a plane table survey on the ground. Where interpolation is used to create the location of the contour lines with the aid of human knowledge substituted for complex rules and priorities. Ground points are identified randomly in a grid fashion and terrain features such as a ditch or toe of slope are line strings made from a series of ground points.

TASK 3 – ACCURACY ASSESSMENT

Lastly, the map needs to be tested for accuracy. Because photogrammetry is not a perfect science, we have to account for the errors that accumulate within any project. We must compare these errors with accuracy standards, which allow for the occurrence of tolerable inaccuracies. Using the principle that errors tend to compensate, we will weigh the various areas that influence total quality. As an example, the camera focal plane is not absolutely flat and the lens system has aberrations in it. If the camera is routinely calibrated, these errors do not create a significant problem.

Guidelines have been published which recommend the maximum allowable error for photogrammetric mapping. Keep in mind that most errors or blunders are traced to human causes, this is important because it is an area that one, can be worked on as a point of personal improvement and two, supervisory staff can allow sufficient time to complete each task properly.

Appendix B

Aerial Photography Planning Process

The aerial photography planning process begins when the need for photographic or mapping products are identified and ends with completion of the delivery of the planning layout maps and files to the contractor and District Surveyor. A typical Mn/DOT flying / mapping project follows these steps:

1. The District Surveyor discusses with the District Design or Operations staff a photo and/or mapping need.
2. The District Surveyor, Design Engineer or Operational Supervisor fills out a *Request for Aerial Photography*, see Appendix D, and creates a map, using a USGS Quad, showing the limits of the photography or mapping if the exact limits are known at that time.
3. The District Surveyor reviews the requests and informs the District Consultant Coordinator who will authorize the release of funds to pay for the flying. A biennial flying meeting usually takes place between the Photogrammetric Unit and the District Office staff to help facilitate this process.
4. The Photogrammetric Unit reviews the *Requests*, creates a Targeting Layout Map, see Figure *i*, (some districts do their own layout map) and creates the associated coordinate file, see Figure *ii*.
5. The Photogrammetric Unit assigns the projects to a flying contractor.

The targeting layout scheme is created by using the photographic or mapping limits map, provided by the District in order to establish the proposed flight lines. If the project is a corridor or highway and the intended area is covered with one flight line or the limits are covered with a single strip of photography, the flight line is centered over the intended object. The perpendicular distance out from the flight line to the wing point is calculated using the following formula:

$D_w = S_p * 3$

Where D_w is the perpendicular distance to the wing point
Where S_p is the Scale of the Photo usually 1" = 250' for Mn/DOT projects
So D_w = 250' * 3 = 750'

The distance between consecutive targets or the target interval is arrived at by the following formula:

$D_{TI} = (F_S - M_S)\ S_P$

Where D_{TI} is the target interval measured along the flight line
Where F_S is the size of the format, which is 9"
Where M_S is the margin safety for overlapping photos, which is 2.6"
Where S_P is the Scale of the Photo, again, which is 250'
So D_{TI} = (9" – 2.6") 250' = 1600'

First, the flight line is centered over the intended coverage area. Second, two wing points (targets) are established perpendicular to and 750 feet out from the flight line at the beginning of the intended photography or mapping limits. Third, 1,600 feet or less from the beginning wing points a vertical control points is needed, 750 feet right or left of the flight line. Today, the department is using a target with total control for this vertical control point. The pattern in step three continues until the wing points are 12,800 feet more or less from the beginning and at this location a new set of wing points are required. Somewhere within each 12,800 foot segment an additional total control target should be set and will be used as a test point. This layout scheme will then continue until the end of the flight strip and to anchor the end of the flight line, a pair of wing points will be placed.

The targeting layout scheme begins to change with the introduction of an intersecting flight line and this changes again with the addition of a parallel flight line. Usually the person laying out the targets will take into account for the overlay area and try to reduce the number of targets. Keep in mind that the surveyor always has the flexibility to add more targets to the project.

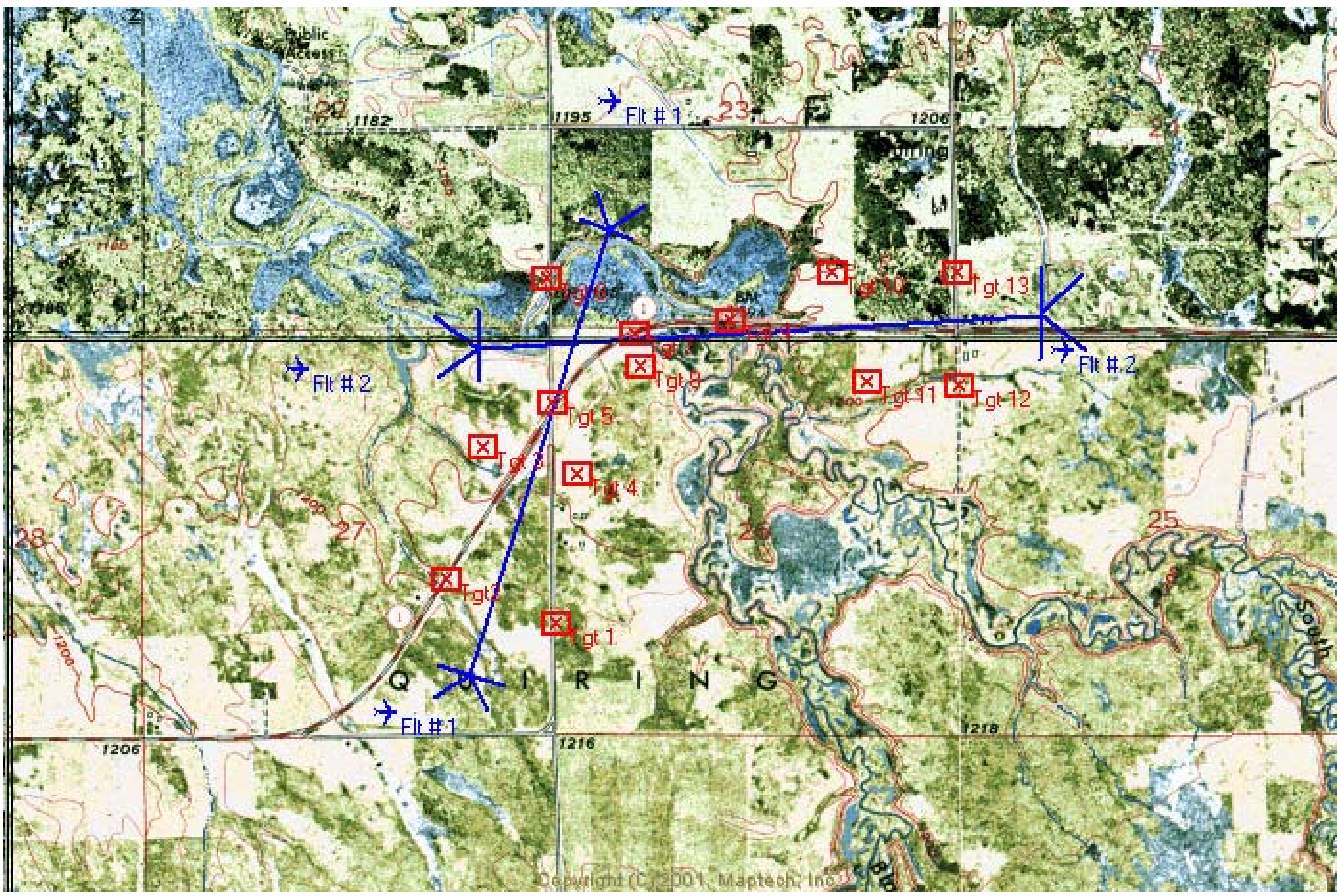

Figure *i*

In most cases, a surveyor will be following the targeting layout map and the suggested target coordinate location will be acceptable. On some occasions the surveyor will need to relocate the target location within a circumference of approximately 120 feet. When the surveyor can not successfully relocate a target within this area, instead of not setting a target try setting two targets, one closer to the flight line and one farther away this protects the work done so that a return trip is not necessary. The surveyor has the freedom of setting additional targets at his discretion; see the Surveying and Mapping Manual, Section 4-4.0115.

For years the Photogrammetric Unit would use a USGS 7-1/2 minute quadrangle map per Surveying and Mapping Manual, Section 4-3.04, and they still work, however these maps are now available in electronic format.

To aid in the preparation of a targeting layout, there are commercial software packages that will produce location coordinates via way point symbols. The Photogrammetric Unit uses such a package called Maptech®. Figure *ii* is an example of a Latitude / Longitude output file for the target way points. A similar file will be prepared for the beginning and ends of the flight lines, which are essential for the pilot. This flight end point file also aids the field surveyors when collecting control point data or test point data.

ASP 03F-5L, SP 0404, TH 1, Tgts.MXF

```
47.8646723, -094.7210891, "Tgt 1", "Tgt1", "", ff, 35
47.8662581, -094.7269591, "Tgt 2", "Tgt2", "", ff, 35
47.8711018, -094.7250439, "Tgt 3", "Tgt3", "", ff, 35
47.8727034, -094.7212927, "Tgt 5", "Tgt5", "", ff, 35
47.8700514, -094.7200169, "Tgt 4", "Tgt4", "", ff, 35
47.8740164, -094.7166471, "Tgt 8", "Tgt8", "", ff, 35
47.8734648, -094.7044949, "Tgt 11", "Tgt11", "", ff, 35
47.8732921, -094.6995422, "Tgt 12", "Tgt12", "", ff, 35
47.8771546, -094.7215987, "Tgt 6", "Tgt6", "", ff, 35
47.8751891, -094.7169531, "Tgt 7", "Tgt7", "", ff, 35
47.8756372, -094.7117455, "Tgt 9", "Tgt9", "", ff, 35
47.8773612, -094.7063328, "Tgt 10", "Tgt10", "", ff, 35
47.8773953, -094.6996946, "Tgt 13", "Tgt13", "", ff, 35
```

Figure *ii*

The Targeting Layout Map is sent to the District Surveyor along with an electronic file for the location of the targets, this usually takes the form of Latitude & Longitude and MNCON will convert from this format to the appropriate Minnesota County Coordinate System. The appropriate flight line file is sent to the flying contractor. Contact is made between the District Surveyor and the flying contractor as to weather conditions, target layout status and special concerns, see the Surveying and Mapping Manual, Section 4-3.06. It has happened, although this is rare, that not all targets are placed when the flight occurs. In this case, extra control shots will be required from the District Surveys Office in order to supplement the aerotriangulation process.

Appendix C

Targeting Procedures

There are two ways of generating ground control from aerial photography. The first is to use existing photography, locate suitable image points and have the surveyor establish coordinates for those points. The second is to set the targets that will appear in the photographs. Targets are the preferred method employed by Mn/DOT, the background of this decision is found in the Surveying and Mapping Manual, Section 4-4.0101. First, the target a “well defined” image leading to more accurate photographic measurements. Second, an image point on the photograph may be misinterpreted and could create an error that may be difficult to track down or it may have been destroyed during the time between when the photograph was taken and when the surveyor enters the field to locate the point. There are situations that occur when a project falls under certain time constraints and the only recourse is to use the method of establishing control from existing photography, knowing and identifying what is required is essential in order to have a be successful project.

After the planning process has been completed the District Surveyor will assign a crew to place the targets on the ground at the general locations per the targeting layout map. In reviewing the targeting layout map the first thing that comes to mind is that many of the targets will need to be placed on private property. Where the ownership is private, secure permission through a letter of introduction, a sample letter is provided in Appendix F.

The surveyor should be able to get an idea as to the number of targets that can be painted on a hard surface and those hard targets that belong in a field, pasture or other grassy area. There are many ways that targets should be affixed to the ground and the choice of the material is up to the surveyor. Most District Survey Offices have a stencil for painted targets and prefabricated target material for other situations; this may not be the case everywhere. The first consideration however is to length and width of the target which the following equations will guide the surveyor as to the specific minimum requirements.

Width = S_p * 0.002
Where S_p is the Scale of the Photo (Mn/DOT design standard 1” = 250’)
So Width = 250’ * 0.002 = 0.5’

Length = 10 * W
Where W is the Width
So Length = 10 * 0.5’ = 5’

These two equations come from the textbook *AERIAL MAPPING* by Edgar Falkner, 1995. The Surveying and Mapping Manual shows the targets as approximate and relative to the photo scale in Figure 4-4.0112.

Depending on the amount of time available to the survey crew, the placement of the target may be aided by a GIS grade (2-5 meter accuracy) survey instrument using Latitude & Longitude. A more economical use of time may be to convert the Latitude / Longitude to the appropriate Minnesota County Coordinate System and using a Real

Time Kinematic (RTK) system to navigate to the location and set the target while making the initial observation. There is nothing sacred about the exact coordinate value from the planning process, this is a guide and the surveyor should look for the best available position within 100 feet. An example would be, when the coordinate value directs the placement of the target, per the coordinate value, under a tree, it is imperative that the surveyor use some common sense and move the target to an open area that is flat and representative of the ground and with a clear view of the sky. An 45 degree unobstructed view will be adequate.

Next, is the choice of targeting material. The fastest, longest lasting and least objectionable is the painted target shown as Figure *iii*. A comment on this photo would be to not paint the letters "TGT", it is obvious that it is a target and reduce the size of the number 18. Place a P.K. nail marking the center of the target that will stay in place long after the paint has worn, evidence should remain for a few years and this may be critical when doing checks after the fact. Only apply paint on dry, hard surfaces. From a maintenance point of view, a painted target can be inspected easily and touched up with a broom or by adding fresh paint. For most instances, white paint on black bituminous is the norm but when concrete is new, black paint often works well.

Figure *iii*

For areas that can't be painted, the surveyor's choice of material will depend on the circumstances that are particular to the project area. In the predominately agricultural areas, the choice may be one of a disposable material, such as Tivek®, see Figure *iv*. This use once only material is economical, due in part to the fact that farmers need to get into the fields around the same time as the flights occur and that some of the targets are likely to be destroyed without notice. Buying this material by the roll, usually 4-foot lengths, means that 8 – 6" rolls are ready for easy use in the field. A staple can be forged out of many types of material, ranging from wire to wood and nailed to the ground.

The down side is that the Tivek® material can rip in extremely windy conditions and is difficult to clean if muddy conditions occur, both events can happen in the spring. Although Tivek® is a plastic feeling type of material it does stain and does not wash off easily. There are other materials that may be used for this purpose and if something suitable is discovered, please bring it to the attention of the Photogrammetric Unit.

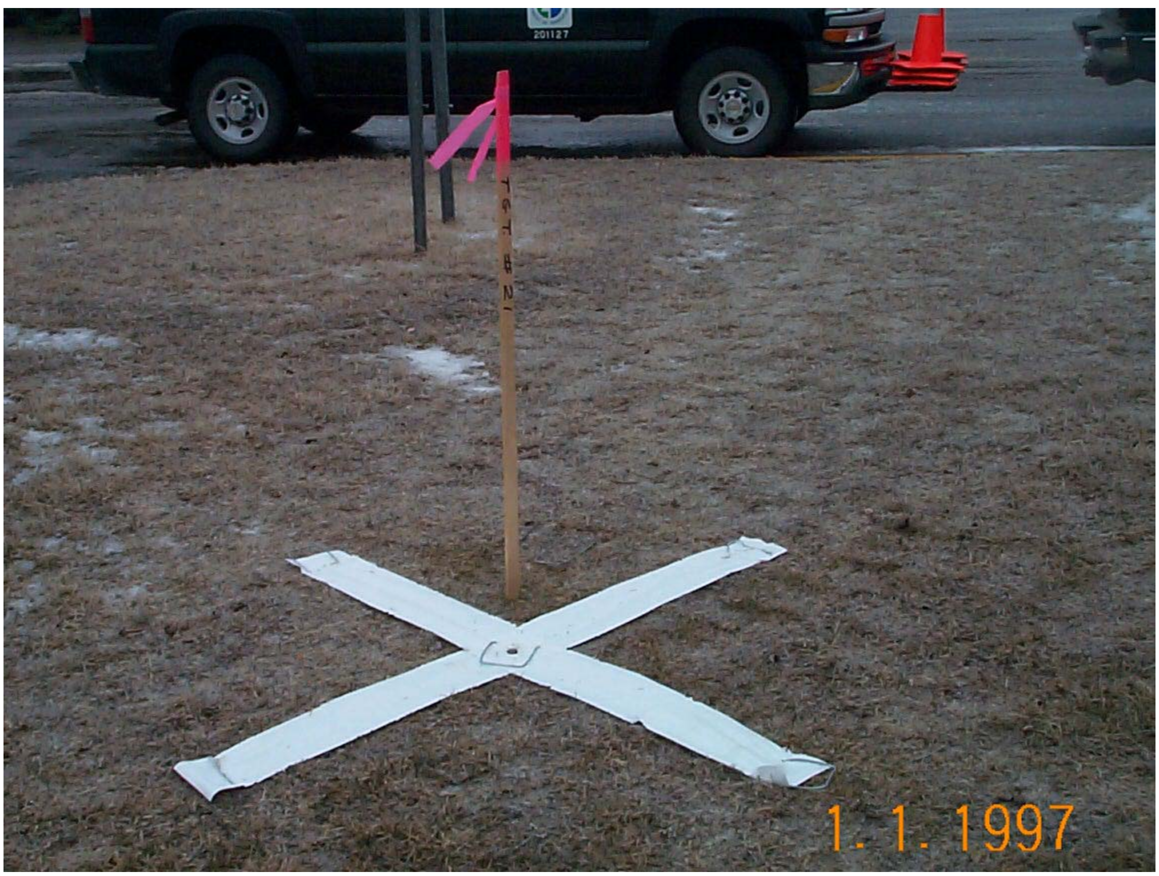

Figure *iv*

In a non agricultural area or areas where there is a likelihood of recovering the target, a re-useable material may be more appropriate, see Figure *v*. The picture shows a cross made of a material that is a compressed wood and paper, stiff with a semi waterproof finish (Masonite®) and a decal that states that the target is the property of Mn/DOT, with a phone number and target number written on it. Other materials that could be used is a white flexible plastic, about ¼" thick or plywood strips that are painted white. The use of a waterproof material makes it easy to wash off when it gets muddy or dirty. A target made of a waterproof or plastic material generally will work better during the pickup process for obvious handling reasons. The target is then nailed to the ground with spikes. If the ground is frozen, the spikes act as an adhesive and the target is likely to stay in place and if laid flat, will survive most normal wind conditions.

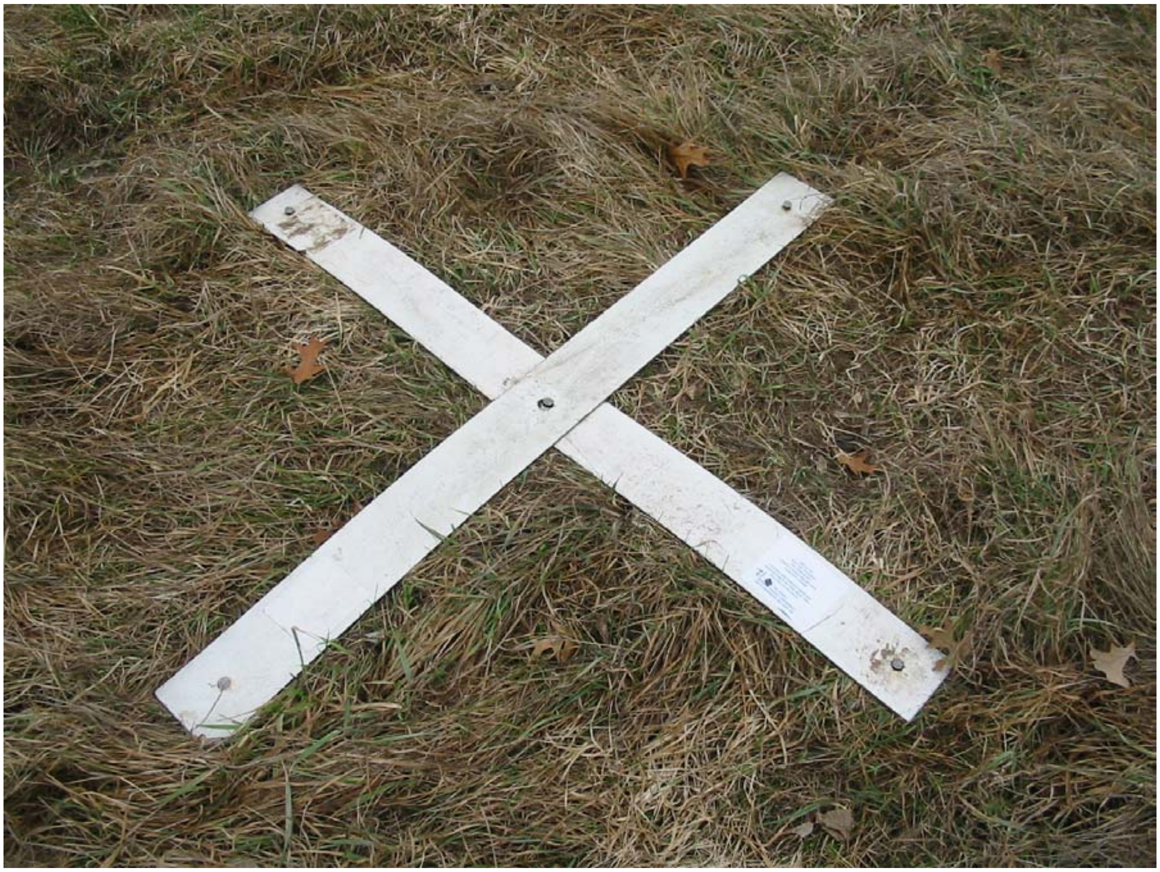

Figure *v*

The hard targets are vulnerable to vandalism, so all in all, the painted target is considered the best for the reasons outlined but only if the conditions and circumstances are right.

Appendix D

REQUEST FOR AERIAL PHOTOGRAPHY

Date: _____ **Survey Section Reviewer:** _____

Requested By: ______ **Phone:** ______

MAPPING: ☐	NON-MAPPING: ☐		PHOTO SCALE: 1" = _____	CO use only
S.P.	C.I.D.	T.H.	COUNTY:	ASP:
				FSM:
NAME OF QUAD MAP(S) OR MAP TECH FILE FOR THIS PROJECT:			APPROX. MILES TO BE FLOWN:	Item:

LOCATION:

Intended use of aerial flight ____________________

Are there previous flights in the area? ☐ YES ☐ NO If yes, previous ASP: ______

Photography Type:

Black & White ☐, Color ☐, Color Infra-red ☐

If Intended Use is For Mapping - Complete The Remaining Form

Is vertical information required on mapping project? ☐ YES ☐ NO

Have you included any non-mapping areas in a mapping flight? ☐ YES ☐ NO

Please provide your best estimate of mapping limits or area of interest to ensure adequate coverage from our office. Detailed mapping limits need to be submitted on the photo indexes that you will receive.

(Note: limits submitted should be mapping limits, not photography limits)

If this project is programmed, please indicate the letting date: ______________

Indicate the type of products that will be required: Ortho Photo (targeted) ☐, Rectified Mosaic (Quad Control) ☐, Plan &/or DTM ☐

REMARKS:

Appendix E

REQUEST FOR PHOTOGRAMMETRIC MAPPING

Date submitted _____

S.P.: _____________ C.I.D.: _____________ T.H. ______ County: _______________ ASP#: _____

Location: ____

Approx. Length in miles: _________, Stationing increases from _____ to ______

Please use the following a checklist for submitting project for mapping.

District Photos submitted with Request (Y/N) _______, Targets marked (Y/N) _______

Target tie sheet submitted (Y/N) ________, Target quad-map submitted (Y/N) _____

TYPE OF MAPPING REQUESTED

Scale: 1"=50' ☐, 1"=100' ☐, 1:500 ☐, 1:1000 ☐, Other (Note: English or Metric)

_____.

Type of Mapping: Plan Only ☐, Plan & DTM ☐, DTM Only ☐.

TYPE OF DIGITAL PRODUCT REQUESTED

Ortho Photo ________ Rectified Mosaic __________

Typical resolution is 0.5 feet, if other needed please specify: _____________

Required Deliver Date: _________________________ Letting Date: ______

Requested by (name): ______________________ District: ________ Phone #: ______

Assigned Designer: ________________________ District: ________ Phone #: ______

Special Instructions: ____

Comments: ____

HORIZONTAL & VERTICAL DATUM

Horizontal Datum: NAD 83(1996) ☐, NAD 83(1986) ☐, Other _____
County Projection & Zone: ____

Vertical Datum: NAVD 88 ☐, NGVD 29 ☐, Other ___________

Appendix F

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Letter of Introduction

Appendix G

Land Cover Types and Codes

The most common land cover categories per the ASPRS Guidelines for Vertical Accuracy Reporting for LiDAR Data, Version 1.0, May 2004 along with the Mn/DOT approved codes are as follows:

COVER TYPES	CODE
Open Terrain (sand, rock, dirt, plowed fields, lawns, golf courses)	L1O
Tall Weeds and Crops.	L2T
Brush Lands and Low Trees.	L3B
Forested Areas fully covered by Trees.	L4F
Urban Areas with dense man-made structures.	L5U

An example of each is as follows:

Open Terrain – L1O
Foreground Only – use grass or rock bed distant from structures

Tall Weeds & Crops – L2T

Brush Lands & Low Trees – L3B
Use the area past the bituminous slabs.

Forested Areas fully covered by Trees – L4F

Urban Areas with dense man-made structures – L5U

Appendix H

National Standard for Spatial Data Accuracy

Previous to NSSDA there was the National Map Accuracy Standard (NMAS) which for the vertical element stated that *not more that 10 percent of the elevations tested shall be in error more that one-half the contour interval.* This was sufficient for paper maps with graphic contour lines and published scales. Once digital geospatial data was available, a statistical method was needed for estimating the positional accuracy. This is expressed as the Root Mean Square Error (RMSE) for each data category.

The NSSDA reporting criteria for accuracy is stated statistically as:

Horizontal Accuracy:

$RMSE_x = sqrt[\Sigma(X_{data\ I} - X_{check\ I})^2/n]$

$RMSE_y = sqrt[\Sigma(Y_{data\ I} - Y_{check\ I})^2/n]$, Where:

“$X_{data\ I}$, $Y_{data\ I}$ are the coordinates of the I^{th} check point in the dataset

“$X_{check\ I}$, $Y_{check\ I}$ are the coordinates of the I^{th} check point in the independent source of higher accuracy

“n is the number of check points tested

“I is an integer ranging from 1 to n

$RMSE_r = sqrt[\Sigma((X_{data\ I} - X_{check\ I})^2 + (Y_{data\ I} - Y_{check\ I})^2)/n]$

$= sqrt[RMSE_x^2 + RMSE_y^2]$

$Accuracy_r = 1.7308 * RMSE_r$

Vertical Accuracy

$RMSE_z = sqrt[\Sigma(Z_{data\ I} – Z_{check\ I})^2/n]$

$Accuracy_z = 1.9600 * RMSE_z$

In any particular project the requirement of test points or TPRO’s follow these guidelines:

1. The independent testing must be done by a source of higher accuracy
2. The independent source shall be the highest source feasible.
3. Horizontal accuracy shall be tested by comparing the planimetric coordinates of well-defined points in the dataset with coordinates of the same points from the independent set.
4. Vertical accuracy shall be tested by comparing the elevations in the dataset with the elevations of the same point from the independent set.
5. A minimum of 20 check points shall be tested that reflect a distribution of the complete data set. This means only 1 in 20 points can fall outside the 95% confidence level. The 20 check points would cover a 1 mile project and the increased length of the project would increase the number of test points. There is an additional formula for area, but we have not adopted this as of today.

Currently we will continuing to follow the previous guidelines for the collection of the number of TPRO shots will remain in effect until the flow of the Unit’s mapping activities is uninterrupted due to rework or errors. These guidelines are 25 TPRO’s every

1600 feet in the vicinity of the flight line with one set of 25 TPRO's at the beginning of the flight line and another set at the end. If the data is being supplemented with a source that is of greater accuracy then we relax the guideline on the other hand if the data is being supplemented with a source of lesser accuracy, then the reverse is true.

It is my firm belief that the confidence level that our clients have in the mapping product is higher when they see that the mapping has been tested with a large number of test points verses a smaller number. Take a one-mile long project, under the NSSDA standard the testing criteria would be 1 failed test point out of 20. In the Mn/DOT current testing procedure there would be 100 test points taken and 5 test points could fail to meet the 95% confidence level. Although statistically the two criteria are the same, knowing that the mapping product has been tested against a larger number of test points can raise a person's confidence level. This is important for design engineers who are using a product in which they will be making many critical decisions. A critical point here is that all test points must be taken in various type of terrain. If we were to take all TPRO's on the road surface, which happens to be a critical area in our business, we would end up with a strong statistical statement about the mapping of the road surface. We have to do a better job of identifying the terrain differences that we map and willing to include them in the analysis.

Appendix I

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Geodetic Database Station Sheets

Appendix J

Definitions (see Surveying and Mapping Manual, 4-1.03)

Aerotriangulation: Term frequently applied to the process of determining X, Y and Z ground coordinates of individual points based on measurements from photographs.

Analytical Photo Control: Term applied to photo control when it is produced by analytical aerial triangulation methods. This method reduces the number of ground points required compared to conventional photo control.

Center Point Data: A series of points that are tied in the field horizontally and vertically and are used to adjust the elevations in the photogrammetric process on projects where contours, cross-sections, or DTM's are to be compiled. The points are selected randomly at approximately 200 foot intervals along the length of the mapping and near the center of the proposed construction (or center of the flight strip). They are also taken on cross strips of photography. This is not to be confused with a test profile.

Conventional Photo Control: Term applied to photo control when all of its is obtained by ground survey procedures. Requires more ground points then control extended by analytical methods.

Cross Strip: A flight strip that crosses another. Usually used to extend the photo coverage on a crossroad.

End Lap: The overlap area common to two successive aerial photos in a strip. End lap between successive exposures should average 60%.

Flight Strip: A succession of overlapping aerial photos taken along a single flight line. Flight strips are straight lines: hence many flights may be required to cover a curvilinear section of road.

Horizontal Picture Point: A picture point that is surveyed for horizontal control only. This provides the horizontal position and scale control for mapping.

Image Point: A picture point that is chosen from existing ground based objects after aerial photos are taken. May consist of any well-defined, describable objects whose position can be determined and whose image appears on at least two overlapping photos.

Model: The area of a strip between the centers of two successive photos. This is the area on which stereoscopic coverage is available, i.e., *this area is approximately 800 feet on a 1"=250' scale aerial photo.*

Pass Point: A photo control point mechanically produced in the analytical process and usually not identifiable on the ground. It is used to extend or bridge the horizontal and vertical control from one photo to the next. Pugging is the term used to task to mark the point on the diapositive.

Photo Control: Picture points and center points used to relate the aerial photos to field dimensions in photogrammetry.

Picture Point: A point that can be identified on the photo and is tied to horizontal and/or vertical control in the field. Picture points are used to control the horizontal and vertical control relations on the photos. Examples are targets, poles, manholes and catch basins.

Side Lap: The overlap area common to two parallel strips of aerial photos. Side lap between parallel strips may range from 25% to 45% and should average 35%.

Stereo Model: The three dimensional image formed by the two photographic images of the same terrain taken from different exposure stations. The stereoscopic area is normally formed by the overlay of two consecutive photographs in a strip.

Target: An artificial picture point that is placed on the ground before aerial photos are taken. Usually consists of a painted cross or strips of material laid to form a cross. Each strip or cross member of the target is called a panel.

Target Layout: The quad map sent to the district by the Photogrammetric Unit, with the flight lines and proposed target locations shown (Map Tech software is now the accepted alternative to the USGS guad map).

Target Pairs: Two total control picture points, at the wing point positions, left and right of the flight line, that appear on the same model.

Temporary Control: Third order horizontal control points whose values are the direct result of a survey that started on secondary control and ended on secondary control or any control point that the filed crew intends to be temporary. These points do not become part of the control record and cannot be used outside of their source data file.

Test Point Data: A series of points taken in the field to check the accuracy of the photogrammetric data both horizontally and vertically.

Total Picture Point: A picture point that is surveyed for both horizontal and vertical control.

Trilap: The overlap area common to three successive aerial photos in a strip.

Vertical Picture point: A picture point that is surveyed for vertical control only.

Wing Point: A picture point located toward the edge of a strip of photos rather than on the center of the photo strip.