

Leica Infinity

Training materials – Network Adjustments Advanced Adjustment Concepts



Version 1.0
English

- when it has to be right

Leica
Geosystems

Introduction

The purpose of this document is to describe the advanced network adjustment concepts in Infinity, with more focus on the parameters that affect the network’s reliability.

The first chapter discusses the measurements that are used as observations in network adjustment. The second chapter explains the adjustment parameters. In the third chapter, a detailed description of the network adjustment report is presented along with an in-depth explanation of the statistical tests.

It is assumed, that the reader is already familiar with the Infinity network adjustments module. If not, then the “How to...” tutorials related to network adjustments are recommended.

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1. Before the network adjustment

After the data have been imported in the project, the next step is to proceed to the necessary processing to derive the measurements (referred to as "observations" from now on) that will be used in the network adjustment.

In case GNSS raw data have been collected, a set of suitable baselines need to be processed first, as these are the observations that will be included in the network (namely the Δx , Δy and Δz baseline components). The aim is to organize the field measurements in such a way so that a network of independent baselines can be formed.

In case TPS raw data have been measured, the observations can either be the raw data themselves or the result of an application. For example, if data have been collected through Measured Foresights or Sets of Angles applications, then the user can choose whether to use the result of those applications (that is, the reduced observations) or the raw measurements themselves. This option can be found in the **Adjustments** ribbon tab, under **Advanced Terrestrial**.

In case Level data have been measured, then the level lines are the observations that will be used in the network adjustment. If, however, the level data have not been stored in the instrument, Infinity supports the option of typing in the height differences directly. This option can be found in the **Processing** ribbon tab, under **Height Observation**.

2. Explaining the adjustment parameters

In this section, the adjustment parameters are discussed.

General:

General	
Computation	
Store results immediately after computing	<input type="checkbox"/>
Controls	Constrained
Iterations	
Max. Iterations	3
Iteration Criteria	0.0001 m
OK Cancel	

In **Computation**, the user can select whether the adjustment results will be stored immediately after computing. This option is unchecked by default, as the normal case is that there will be many adjustment runs before reaching the desired result.

The "Controls" option determines whether the control points will be treated as absolutely "Constrained" or "Weighted".

If "Constrained" is selected, then the control points will be kept fixed without receiving any corrections during adjustment. Their standard deviations will be set to zero.

If "Weighted" is selected, then the control points will also receive corrections during adjustment. Their standard deviations will be the ones set by the user.

Notes:

- 1. Fixing the control point coordinates often imposes some distortion on the network.**
- 2. At least three control points need to be available in the project, otherwise treating the control points as "Weighted" will have the same impact on the result as if they were set as "Constrained".**

In the **Iteration** settings, the user can set the maximum number of iterations as well as the threshold correction value for the iterations. It is suggested to keep the default values.

TPS Accuracy Information:

Standard Deviations	
Source for Standard Deviations	Individual
Horizontal Angle	0.0015 gon
Vertical Angle	0.0031 gon
Absolute Slope Distance	0.0100 m
Relative Slope Distance	0 PPM
Centring/Height Errors	
Source for Centring/Height Errors:	Individual
Setup Centring Errors	0.0000 m
Target Centring Errors	0.0000 m
Setup Height Errors	0.0000 m
Target Height Errors	0.0000 m

In **Standard Deviations**, the standard deviations for the observed angles and distances can be set. The users can also define whether individual or default values for all observations will be used.

In **Centring/Height Errors**, the centering and height errors for setup and target points can be set. Again, the users can also define whether individual or default values will be used.

Notes:

1. ***Setting the proper standard deviations as well as realistic centering and height errors is of very high importance, as these values have an immediate impact on the weight matrix of the observations.***
2. ***The more we increase the standard deviations and centering and height errors, the less the weight of the observations will be.***

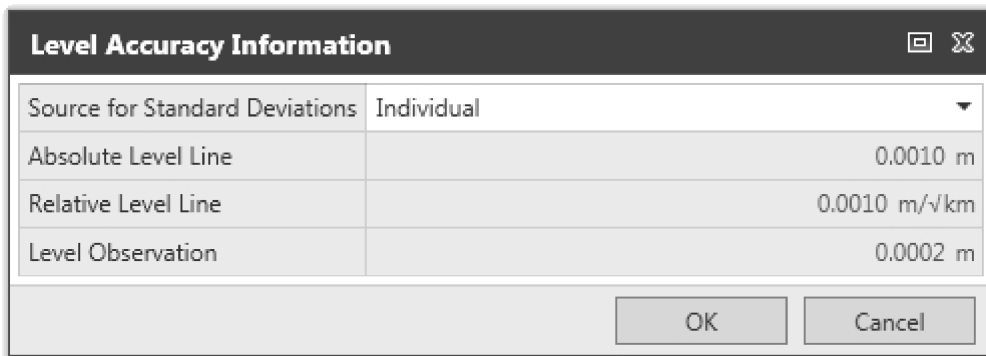
GNSS Accuracy Information:

GNSS Accuracy Information	
Standard Deviations	
Source for Standard Deviations	Individual ▼
Absolute GNSS Baseline	0.0050 m
Relative GNSS Baseline	1 PPM
Centring/Height Errors	
Source for Centring/Height Errors:	Individual ▼
Reference Centring Errors	0.0000 m
Rover Centring Errors	0.0000 m
Reference Height Errors	0.0000 m
Rover Height Errors	0.0000 m
Sigma a priori	
Sigma a priori (GNSS):	10.0000
<input type="button" value="OK"/> <input type="button" value="Cancel"/>	

Just like **TPS Accuracy Information**, the **GNSS Accuracy Information** includes standard deviation and centering and height errors. What is worth mentioning is that, if the "Source for Standard Deviations" is set to "Individual", each baseline is weighted according to the variance-covariance matrix that was calculated along with the processed baseline. If "Use Defaults" is selected, then all the baselines will be weighted relative to their length, using the "Absolute GNSS Baseline" and "Relative GNSS Baseline" user-entered values.

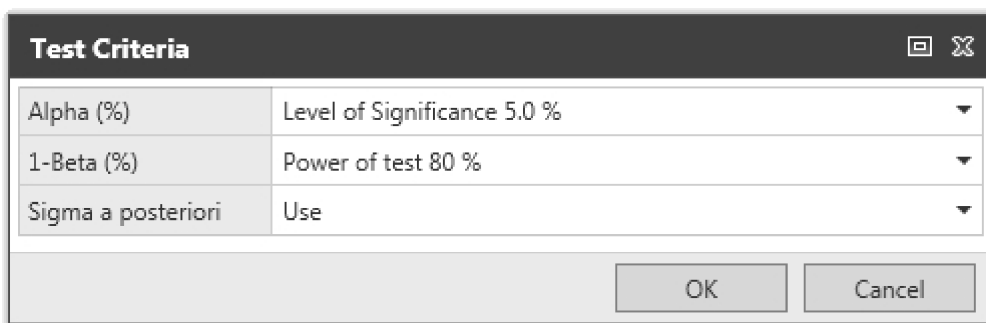
In many cases, the variance-covariance matrices of a processed baseline are too small. The results for the processed baselines can therefore be considered as too optimistic. Before running an adjustment, it is recommended that the baselines acquire a reasonable weight. The "Sigma a priori (GNSS)" serves this purpose: it re-scales the variance-covariance matrix for each baseline by the user-entered value.

Level Accuracy Information:



Just like **TPS Accuracy Information** and **GNSS Accuracy Information**, the **Level Accuracy Information** includes settings for absolute and relative level line standard deviations as well as level observations. Once more, it is worth mentioning that the proper weight for each level line observation needs to be set, otherwise the adjustment results might be unexpected.

Test Criteria:

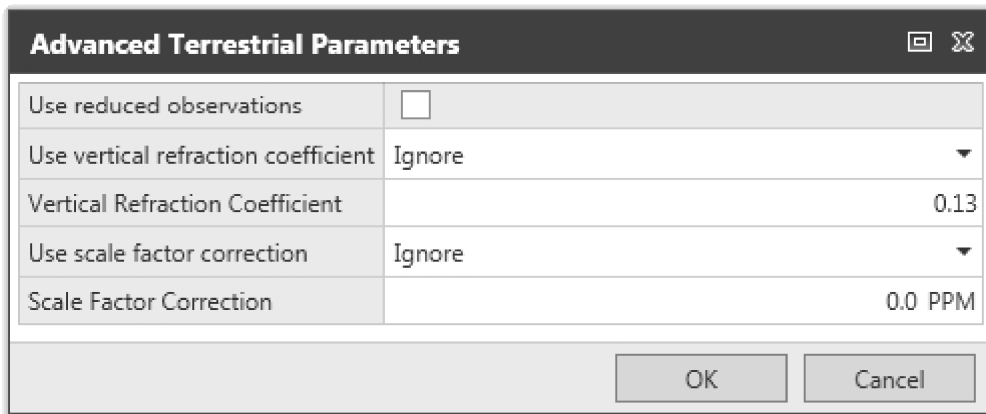


Infinity uses the B-Method of testing for evaluating the reliability of the network adjustment results. The Alpha level of significance is the probability of committing a Type-I error, whereas the 1-Beta is the power of the test against a Type-II error.

As far as the "Sigma a posteriori" is concerned, there are three cases:

1. It can be used to rescale the final variance-covariance matrices. This can lead to unexpected results, if its value is significantly greater or smaller than 1.0.
2. It can be used only if the F-Test fails. This is up to the user, because if the F-Test fails there is always a general problem in the adjustment that needs to be investigated
3. It can be ignored. This will keep the originally calculated variance-covariance matrices unscaled and it is a good choice for the initial inner-constrained adjustment runs.

Advanced Terrestrial:



In case reduced observations are preferred over raw TPS data, the “Use reduced observations” needs to be checked. The standard deviations of the reduced observations will then be used to calculate the weight matrix.

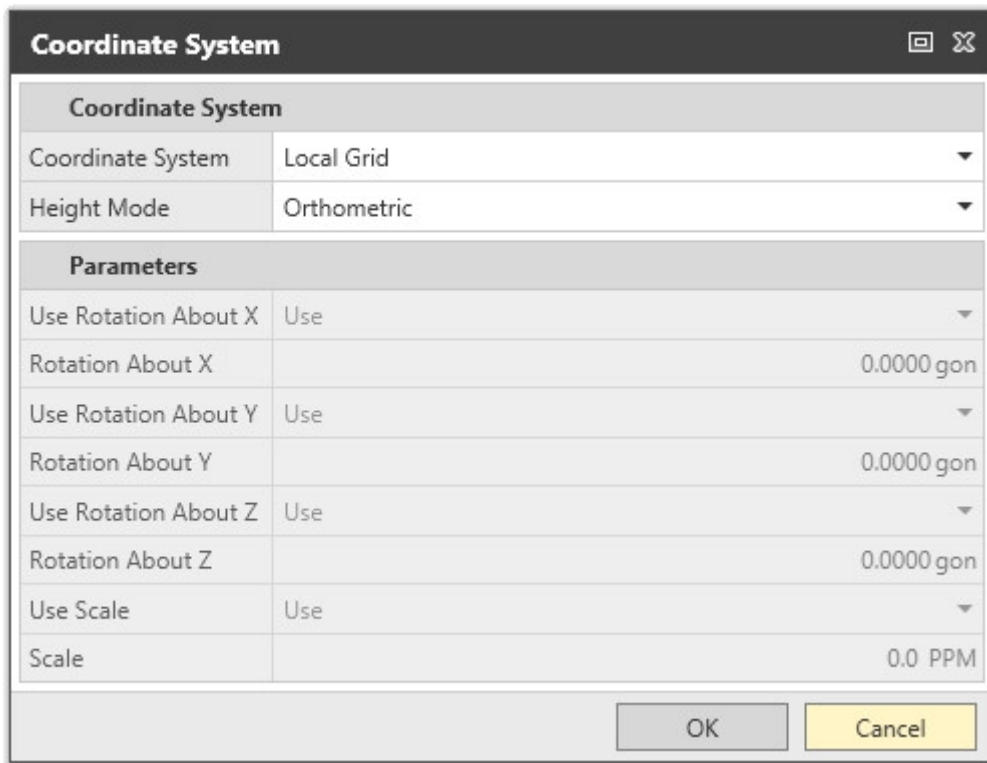
In some cases, it is worth extending the mathematical model of the adjustment, as this can make it more suitable to fit the observations. Two parameters are commonly used: the “Vertical Refraction Coefficient” and the “Scale Factor Correction”.

The “Vertical Refraction Coefficient” can be useful, if small TPS 3D networks are measured. This parameter has an effect on the measured zenith angles.

The “Scale Factor Correction” is useful when GNSS and TPS observations are used in a combined adjustment. More details on this will be given in the next chapters.

What is worth mentioning is that each of the aforementioned parameters can be ignored, computed or used with a value that is user-entered. This provides a flexibility that in many cases is important.

Coordinate System:



One of the most important aspects of network adjustments is to select the coordinate system which the observations will be referred to. This is something different from the coordinate system that is used in the project. The latter is clearly used to project the point coordinates to it, whereas the first one is used to transform the observations from different sources, so that they can be properly combined. As an example, we take the case where GNSS and TPS observations need to be used in a combined adjustment. The GNSS observations are referred to a geocentric coordinate system. On the other hand, the TPS observations are referred to a topographic plane. In order to use the two observation groups in a combined adjustment, it is necessary to transform both groups to a common reference. Since the power of GNSS observations is that they can be treated like true 3D vectors, we choose to transform the TPS observations from the topographic plane to the same geocentric system the GNSS observations are referred to. This geocentric system is the "WGS84" option in the "Coordinate System" dialog box.

The "Local Grid" option is a good choice when only TPS data are adjusted or when TPS and Level data are combined. In this case, the GNSS data will not be used and a warning message will appear.

The "Local Geodetic" is a good choice when GNSS, TPS and even Level data need to be used in a combined adjustment, provided that there are at least 3 control points whose coordinates are known in this "Local Geodetic" system. This option offers great flexibility as it extends the mathematical model of the adjustment so that it includes additional rotation and scale parameters to transform the observations to this "Local Geodetic" system.

Notes:

- 1. A local coordinate system needs to be set as Master in the project in this case.**
- 2. The transformation used in this local coordinate system has to be either a Classical 3D or None for this option to become active.**

The additional rotation and scale parameters can be either computed or used with a user-entered value.

What is also interesting is that either Ellipsoidal or Orthometric heights can be used. This is very important when GNSS and Level data are combined. The "WGS84" or the "Local Geodetic" (in case enough control points and a suitable coordinate system are available) option could be used as the coordinate system for the adjustment.

In this case, the orthometric height differences will be transformed via the geoid to ellipsoidal height differences; they will be adjusted in WGS84 (or the Local Geodetic) and then transformed back to adjusted orthometric height differences to calculate correct orthometric heights for the points.

3. Adjustment types

Depending on the dimension of the data, Infinity supports the following types of adjustment:

1. 3D (Full) adjustment: this type can be used to adjust pure GNSS data or a small TPS 3D network or combined GNSS, TPS and Level data.
2. 2D adjustment: this type is more suitable to adjust TPS data and ignore the point heights.
3. 1D adjustment: this type can be used to adjust pure level data or combined level and trigonometric height differences.

Infinity can also run adjustments in two steps. Two additional adjustment types are also supported: 2D+1D and 1D+2D. To put it simply, when TPS and level data are combined, the point positions can be determined from the TPS observations, whereas the point heights can be determined from the level data. Thus, the trigonometric height differences can be ignored, if necessary.

Depending on the constraints imposed on the data, Infinity supports three types of adjustment: "Inner Constrained", "Minimally Constrained" and "Constrained".

"Inner Constrained" is the case that a special type of minimum constraints called inner constraints is used in the adjustment. In this case, the corrections the point coordinates receive are the smallest possible. Also, all control points are considered as unknowns.

“Minimally constrained” is the case that user-defined minimum constraints are used in the adjustment. In this case, the corrections the point coordinates receive are the smaller than the ones calculated in a constrained adjustment. An example of minimally constraining a network is to fix one control point in height and adjust level data in 1D, or to fix one control point in position and height and adjust GNSS data.

“Constrained” is the case that all or more than the minimum required control points are kept fixed in the adjustment.

As already mentioned, some distortions are expected in the network when more than the necessary constraints are imposed on the data. This causes some bias in the coordinate estimations and it is for this reason that this type of adjustment should be avoided, when checking for possible outliers in the observations.

4. Explaining the network adjustment report

After running an adjustment, a report can be created from the **Reports** ribbon bar button.

The network adjustment report comprises the following sections:

- Project Details
- Adjustment Settings
- Adjustment Summary
- Input Data
- Adjustment Results
- Testing and Estimated Errors

Project Details:

All the project details can be found in this section: General, Customer details, Master coordinate system, etc.

Adjustment Settings:

This section includes all the necessary information on settings used in adjustment. In summary, information on the control point treatment, the adjustment dimension and type, the coordinate system the observations are referred to, the height mode as well as the standard deviations and the testing criteria is displayed. There is also information on whether reduced observations are used or not.

Adjustment Summary:

This section includes all the necessary information regarding the adjustment summary. Total number of unknowns, of observations and of constraints as well as degrees of freedom, optimization criterion and sigma a posteriori can be found here. What is also important is that the F-Test and Chi Square Test actual and critical values are included along with the critical values for W- and T-Tests.

Notes:

- 1. If the calculated value of the F-(or the Chi Square) Test exceeds its critical value (upper or lower boundary respectively), then it will be marked in **bold red**.**
- 2. The sigma a posteriori is the square root of the result of dividing the optimization criterion by the degrees of freedom.**

Input Data:

This section includes the approximate values for the point coordinates as well as the initial observations with the standard deviations. As already mentioned, the standard deviations are used to form the weight matrix.

Adjustment Results:

This section includes the adjusted point coordinates with their standard deviations, the absolute error ellipses, the external reliability values and the adjusted observations. If GNSS baselines have been included in the adjustment, the baseline vector residuals can be also found in this section. Next to each observation, the W-Test values (and T-Test values for 3D observations) are shown.

Note:

By default, the error ellipses are calculated at 39.4% confidence level, whereas the 1D-coordinate elements are calculated at 68.3%.

Testing and Estimated Errors:

This section includes important information on the reliability of the network. Reliability is divided in two kinds:

- **Internal reliability**, which is expressed by the Minimal Detectable Bias (MDB). The MDB presents the size of the smallest possible observation error, still detectable by the statistical test (data snooping) with a probability equal to the power 1-Beta of the test. A large MDB indicates a weakly checked observation or coordinate. Thus, the larger the MDB the poorer the reliability. If an observation is not checked at all, no MDB can be computed and the observation is marked as a 'free observation'.

- **External reliability** is expressed by the **Bias to Noise Ratio** (BNR). The external reliability is used as a measure to determine the influence of a possible (undetected) error in the observations on the adjusted coordinates. The BNR of an observation reflects this influence, whereby the size of the observation error is defined equal to the MDB of that particular observation. The BNR is a dimensionless parameter combining the influence of a single observation on all coordinates. The BNR can be interpreted as the ratio between reliability and precision.

An important property of both the MDB and BNR is that they are **independent** of the choice of the control points.

The **Red** expresses the redundancy (%) of each observation. The higher the redundancy the more controllable this observation is. Theoretically, the redundancy of an observation between two control points that are kept fixed should be 100. On the other hand, the redundancy of a free observation should be 0.

The **W-Test** is a one-dimensional statistical test that is suitable for detecting possible outliers. Its critical value depends on the significance level α_0 .

Essential for the B-method of testing is that an outlier is detected with the same probability by both the F-Test and the W-Test. For this purpose the power $1-\beta$ of both tests is fixed on a level of usually 0.80. The level of significance α_0 of the W-test is also fixed, which leaves the level of significance α of the F-Test to be determined. Having α_0 and $1-\beta$ fixed, α depends strongly on the redundancy in the network. For large scale networks with many observations and a considerable amount of redundancy, it is difficult for the F-Test to react on a single outlier. The F-Test, being an overall model test, is not sensitive enough for this task. As a consequence of the link between the F-Test and the W-Test by which the power is forced at 0.80, the level of significance α of the F-test will increase. Considering the above, it is common practice to always carry out the data snooping, no matter the outcome of the F-test.

The W-Test works well for single observations, e.g. directions, distances, zenith angles, azimuths and height differences. However, for some observations such as GNSS baselines, it is not enough to test the DX-, DY-, DZ-elements of the vector separately. It is imperative to test the baseline as a whole as well. For this purpose the **T-Test** is introduced. Depending on the dimension of the quantity to be tested, the T-Test is a 3- or 2-dimensional test. As with the W-Test, the T-Test is also linked to the F-Test by the B-method of testing. The T-Test has the same power as both F- and W-Tests, but it has its own level of significance and its own critical value.

The **Estimated Error** is the size of the error responsible for the rejection of an observation or known coordinate. It is a useful tool, yet it should be handled with care:

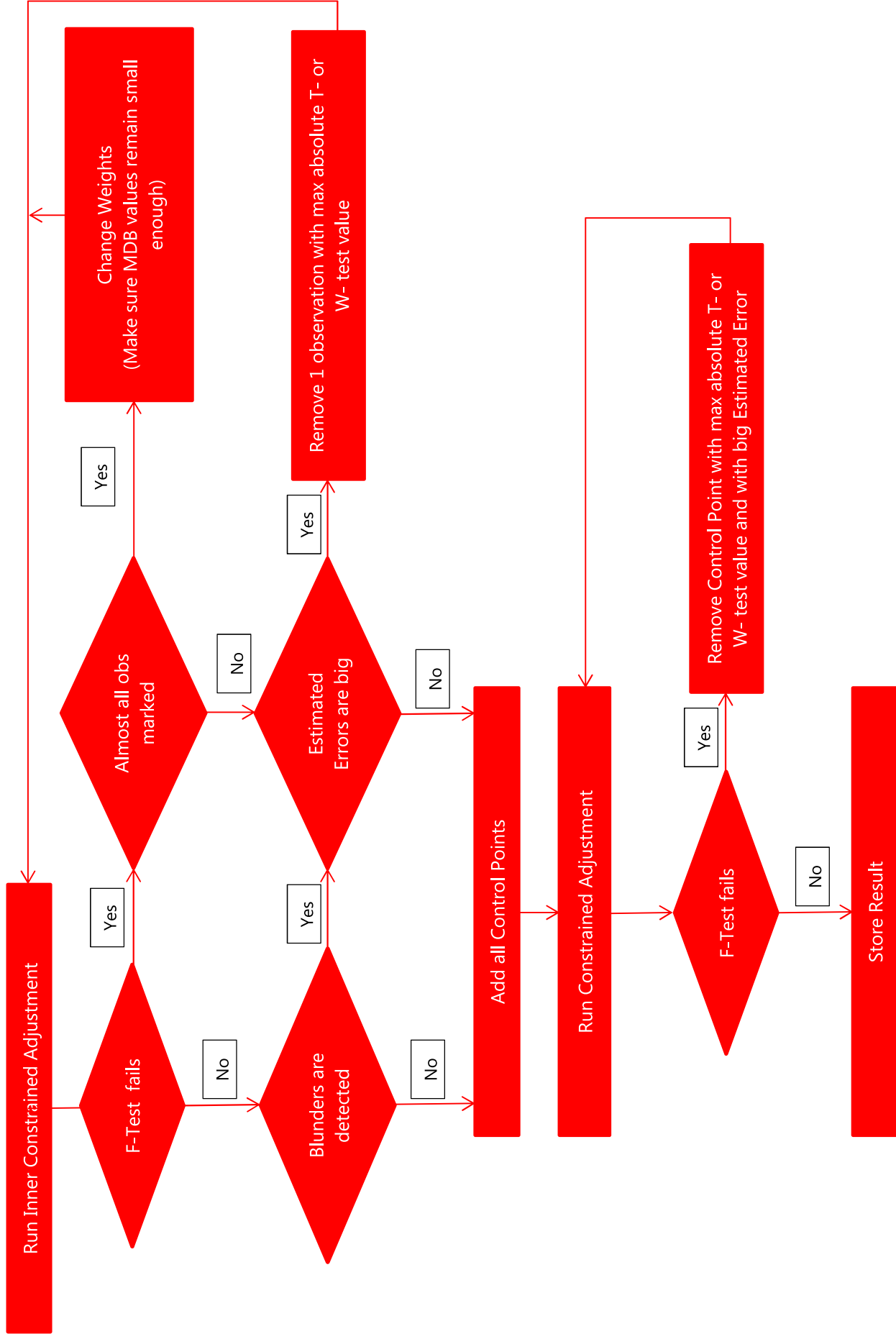
- Only the estimated error associated with the largest W-test or T-test should be considered.
- As far as the W-test is concerned, the Estimated Error is based on the conventional alternative hypothesis that just one observation or known coordinate contains an error. Consequently, if more errors are present in the network, the result of the estimation could be meaningless, unless errors have been made (geographically) far apart.
- As far as the T-test is concerned, the Estimated Error is based on the hypothesis that just one GNSS baseline or known station contains an error. Consequently if more errors are present in the network the result of the estimation could be meaningless, unless errors have been made (geographically) far apart. The test results and Estimated Errors are only meaningful when observational errors have been filtered out in the foregoing free adjustment and testing phase. This is why you always need to run an inner- or a minimally constrained adjustment before adding the control points.

Notes:

1. ***It is desirable that the BNR is homogeneous for the entire network.***
2. ***The MDB and the BNR values are affected by the selection of the weight matrix.***
3. ***Always strive to retain sensibly small MDB values or else the network might become very insensitive in detecting outliers.***
4. ***It is advised that the Red value exceeds 20 for all observations.***
5. ***There might be cases that an observation is marked as a possible outlier, but the estimated error is small –even smaller than the MDB value for this observation. In such cases, it is up to the user to decide whether this observation is really an outlier or not.***

5. Proposed workflow for running network adjustments

The proposed workflow for running network adjustments is shown in the following chart:



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