I Measured Between Those GPS Stations and It Doesn't Check!

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I received a phone call today from a person I have known for a long time who had a problem. He said, "I'm doing a route survey and I hired a GPS contractor to set control for the project. He set GPS control at 300 to 700 feet intervals along the route. I later set up on one GPS station and backsighted to another to establish supplemental stations before tying into other GPS stations. When the field crew measured between the GPS stations, the field distance often differed from the computed GPS distances by as much as 0.07 of a foot. I know that the inverse computation between the State Plane Coordinates yields the grid distance. I have corrected my field distances for vertical angle, grid and elevation factors and they still have this much difference. What gives? If GPS is supposed to be so much more accurate than conventional surveying how can I measure distance more accurately using EDM equipment? Which is more error prone, the GPS or the conventional measurements?"

The answer lies in understanding the accumulation of errors in conventional measurements. This can best be understood using a hypothetical conventional traverse run along a road starting at Station "A" and backsighting station "B". The traverse includes setting 11 new stations at intervals of between 300 and 600 feet apart and tying into station "C", foresighting station "D".

Next, the same type of traverse is run down the opposite side of the road using the same four points as beginning and ending stations, but running through station 6 of the first effort.

With the average length between the stations being 450 feet, the total length for each traverse would be about 1 mile. For the purposes of this discussion, assume the following:

a) the starting and ending coordinates and azimuths are of very high quality, so their contribution to the total error is very small;
b) the standard errors for the angles are 3 seconds;
c) the possible distance errors are 0.01 of a foot;
d) the centering error for the instrument and targets is 0.01 of a foot.

These assumptions are valid given the equipment in general use today and the techniques widely used by modern surveyors. They will reflect typical error sources for most carefully run traverses today.

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These errors, when combined and accumulated through the line of traverse, create a possible error that has the shape of an ellipse at each station. This ellipse encompasses the area within which the theoretical true coordinate value lies, given the errors that impact its measurement. When the ellipse is inflated to the point that there is a 95% chance (that's 19 chances in 20) that the true position will fall within it, it has a long axis of 0.20 of a foot at station 6. [If anyone is interested in how that is determined, I will write another essay explaining.] This long axis is perpendicular to the direction the traverse is running because the 3 seconds possible error in the short sights and the centering errors for the instrument and targets accumulate to cause most of the size for this ellipse. You can see that with the true value of station 6 being somewhere in an ellipse of this size for each of the 2 lines of traverse run, it would not be surprising to find a difference in the coordinate values of station 6 in one traverse versus the other of 0.20 - 0.30 of a foot. Hold that thought.

The other part of this dilemma is the GPS work. The positions for two or more stations are determined by using many distances to 4 or more satellites collected at the same time, so that the errors can be cancelled in the processing of the data. The error source for each GPS station is much simpler and will accumulate at a very small rate as compared to conventional traverse. These errors are 0.035 of a foot, plus 2 parts per million times the distance between the GPS stations, plus 0.01 of a foot centering error for the instrument. The total root mean square error for the position of each GPS station will fall in a circle that has a diameter of less than 0.04 of a foot.

Even through traverse station number 6 has a possible error of 0.20 - 0.30 of a foot, you would probably never see it. The only things you usually have to check the values against are the foresight and backsight measurements, and they have only been adjusted by the misclosure of the traverse proportioned into its total length. Note: The misclosure of a traverse may or may not reflect the errors that are really in the traverse.

> "There is good luck and bad luck in traverse closures but without good work you usually don't have good luck."
>
> Dragoo's First Law of Traverse Analysis

On the other hand, the GPS station positions have much greater accuracy, falling in a circle of less than 0.04 of a foot. When you measure the distance between them with conventional measuring devices (EDM or tape), it is possible to detect the different places that these positions fall in the error circle. This is only a problem when you use two GPS stations that are close together to determine an azimuth from which to extend conventional traverse. When these stations are near one another, the distortion in the azimuth caused by the potential error of 0.04 of a foot in each station can be a problem. This occurs when a traverse tied to the GPS stations is carried far enough that the position error is magnified because of the distortion in the starting azimuth. The key here, if the GPS stations are close together, is not to carry the traverse too far. These factors should change the way surveyors evaluate the quality of traverses - away from the traditional ratio of error test and toward the positional accuracy test.

These are techniques to prevent these problems before the surveyor gets his GPS results. There are also ways to minimize these problems if the GPS information has already been obtained.

The best method of prevention is to measure the distance between the intervisible stations after the GPS observations are made and include both values in the adjustment. Because of their greater accuracy, distances can be given greater weight in the adjustment and the final positions will have very close agreement with the conventional distances. If an EDM is used, the distances should be carefully measured and corrected for instrument contact, reflector constant, temperature, pressure, vertical angle, height of instrument, and height of target, with properly calibrated tribrachs. This will ensure that the quality of the GPS observations is not compromised.

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A second method of prevention is to avoid setting intervisible GPS stations. If at least one station needs to be set between two GPS stations, the potential error of less than 0.04 of a foot for each station will not be as readily detectable. This will especially be true for GPS stations occupied in the same session where the relative error between the stations is less than 0.07 of a foot.

The last method handles the problem in the adjustment process. This is done by using a true lease squares adjustment package. When the adjustment is set up the coordinate values on the GPS stations are not fixed rigidly but are assigned a small standard error of 0.03 of a foot. The distances are assigned standard errors pursuant to their quality (which is generally somewhat better than the 0.03 of a foot). The result is that, in the final adjustment, the GPS stations will have new values that will compare much more closely to the conventional distances.

In summary, conventional single line of sight measurements is more accurate than GPS measurement, but GPS coordinates are more accurate than coordinates derived from conventional measurements. Control for smaller scale projects would benefit from having both methods incorporated in the survey and the adjustment.