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**DISCUSS THE BENEFITS OF GPS OVER OTHER FORMS OF EQUIPMENT FOR MEASURING.**

- **Highly Accurate And Fast Process:** The GPS technology supports the surveying process by providing data with highest accuracy due to the multi-channel design. This equipment is also faster when compared with conventional surveying equipment.

Because the data collection process is faster, the time for getting final results and making decisions is understandably shorter and all of this is done with the minimum chance for mistakes which are not uncommon with conventional methods, as is the example with the use of the limited line-of-sight, for instance.

Despite all the painstaking traditional work, a single mistake would be enough to impact the whole project without ever being discovered. With the application of GPS in land surveying this is no longer the case and as a result, it improves the quality of work. It's no surprise the surveying and mapping community registered an immediate increase in productivity upon adopting GPS surveying methods.

- **Time, Cost And Labor Saving Technique:** The traditional and conventional surveying can be a very costly and time consuming process, to say the least. In the past, surveyors had to make several visits to one site in order to use each and every piece of equipment, going step by step to gather accurate data.

This advanced GPS surveying reduces both equipment and labor that was once required for completion of a surveying task thus it's a preferred option if you want to reduce costs altogether. Nowadays, a single surveyor can complete all the tasks in one day, something that took a whole team to do in a longer period in the past.

Moreover, given that there's wiser use of the resources it's safe to say it contributes to sustainability too. Along with this, despite the complexity of this new technology it's still created to be user-friendly, meaning the additional advantages of GPS are lesser needs of highly trained crews since even less trained operators can do the job.

Not Affected By Weather Conditions – Another huge benefit is that the GPS surveying is not affected by weather conditions like snow, rain, high or low temperatures. Unlike the traditional surveying techniques, the GPS surveying is not affected by constraints such as the line of site visibility between the survey locations.

- **Portability:** It's necessary to point out the reduction of weight in this kind of survey equipment which certainly comes in handy when one has to pack up and get going to the site where surveying ought to take place. Before, when all sorts of

equipment were required, all the weight was certainly slowing the process down.

Then of course, there was the risk of damaging it, something you won't have to worry about with the latest GPS devices, designed to be of quality and provide longer use. Best of all is their design keeps decreasing, though not at the expense of efficiency or price.

- **Location and Area Size:** As can be seen with the surveying of the waterways and the coasts, even with few land-based points you can still collect data and carry out the process properly. Since it's the kind of technology that allows for accurate work over long distances, there's no need to keep relocating the base unit to be able to perform a survey at remote areas, something unimaginable years ago. In other words, the amount of operational limitations is significantly reduced. On the plus side too, regardless of the size of the area, it can be even a large one, the level of accuracy remains the same with GPS technology.
- **Economic Gains:** As mentioned, the adoption of these techniques brings about numerous benefits of GPS, among which the reduction of costs but it's important to note the economic gains go way beyond this, considering the improvements in productivity thanks to GPS applications and GNSS in general in surveying, asset mapping, machine guidance, mining, agriculture and automation of operations brought to an increase in the Australian GDP, adding between \$2.3 billion and \$3.7 billion in 2012. It's projected that this amount is going to increase significantly as of next year, thanks to the increased use of this technology, its contribution expected to reach between \$7.8 billion and \$13.7 billion.

All in all, the ongoing modernization and development of the GPS technology as well as its connection with other techniques will make the GPS surveys even more useful and widely adopted worldwide in the near future.

## **TYPE OF ERRORS ASSOCIATED WITH ABSOLUTE GPS POSITIONING MODE**

1. **System errors:** are those errors that will affect every positioning activity regardless of the specific location of a particular receiver. System errors originate from inaccuracies in the positions of the satellites, the GPS signal and the propagation of the signal through the earth's atmosphere. Most of these errors can be eliminated if GPS positioning is performed in a relative mode and with dual frequency receivers. GPS surveys are always made relative to a known control point, thus, many system errors cancel out. System errors include:
  - **Ephemerides Errors** – To compute a position with GPS, it is necessary to know the exact position of each observed satellite. The positions of the satellites derived from the broadcast navigation message (broadcast orbits), are predictions of where the satellites are expected to be. These predictions could have an error of a few meters. For most practical purposes these errors are insignificant in a relative (differential) positioning mode. Precise orbits that have typically sub-decimeter orbital accuracy may be required for specific projects.
  - **Satellite Clock** – Precise GPS positioning depends on precise timing devices since one of the GPS observables is time. The double-differencing data processing technique (processing

observation data from 2 satellites and 2 receivers simultaneously) can eliminate the impact of this error. In GPS surveying, the standard positioning computation is double-differencing.

- **Tropospheric Delay** – The troposphere is the lower part of the atmosphere extending from the Earth's surface to a height of approximately 15 km. This is an electrically neutral and non-dispersive medium for frequencies as high as about 30 GHz. Within this medium, group and phase velocities of the GPS signal on both L1 and L2 frequencies are equal. The GPS satellites transmit on two L-band frequencies: L1 = 1575.42 MHz and L2 = 1227.6 MHz.

## 2. Receiver Dependent Errors

- **Receiver Clock Error** – As mentioned earlier, precise timing is essential for GPS positioning. High quality clocks are very expensive and even they are subject to errors. Receiver clock errors can be eliminated by utilizing the double differencing computation method.
- **Receiver Noise** – GPS receivers are not perfect devices. Some level of noise always contaminates the observations and produces positioning errors. The “carrier to noise power density ratio  $C/N_0$ ” value determines how well the tracking loops in the receiver can track the signal and, hence, the precision of the observation. Nominal GPS receiver  $C/N_0$  values are in the 40 50 dB-Hz range.
- **Antenna Phase Center** – The cross hair of a GPS receiver is the antenna phase center. The position that is determined with GPS is the position of the antenna phase center. Every antenna is calibrated by the vendor to determine the offset between the center of the physical center of the antenna (used to place the antenna directly above a point) and the phase center. Each antenna has a setup orientation mechanism to enable the user to orient all antennas used in a given session to the same (usually north) direction. If this is done and the same type of antenna is used in the session, the antenna phase error can be eliminated. This is

one of the reasons why it is not recommended to mix antennas from different manufacturers in a given session, unless this error is known and corrected for.

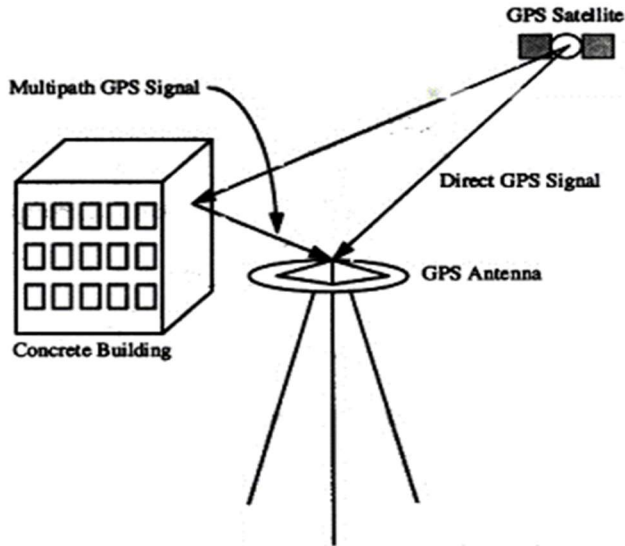
- **Bulls-Eye Level Bubble Collimation Error** – The integrity of the bulls-eye level bubble on the 2-meter fixed height pole and the rover bi-pod pole must be checked before, after and during the project (if suspect). The findings must be documented in the final survey report. An out of adjustment bubble can cause an antenna centering error of several centimeters.

### 3. Errors Due to Point Selection

The selection of points to be measured with GPS is not a trivial matter. The rules of point selection in traditional surveying, mainly maintaining line of sight, do not apply in GPS surveys. Since the direct line of sight has to be with the satellites, points have to be selected in such a way that the clearest signal is received at that point. The following are errors that can impact the results of GPS surveys:

- **Multipath** – Multipath is receiver-satellite geometry dependent, hence the effect of the multipath error on positioning will generally repeat on a daily basis for the same baseline. A signal can arrive at a receiver directly from the satellite, but also from a nearby reflective surface. The reflected signal travels a longer path than the direct one, which results in an observation error. The point to be GPS occupied must be selected in such a way that it is not adjacent to a reflective surface. If possible, avoid locations of stations near large flat surfaces such as buildings and large signs.

For this reason, the vehicle used during the survey should not be parked near the GPS antenna, or the antenna should be mounted higher than the vehicle. Longer observation times can help “average out” multi-path error.



Multipath Example

- **Obstructions** – There are two types of obstructions that may interfere with GPS signals. The first is a solid obstruction that completely blocks the antenna from the incoming signal. This will cause fewer actual observations to fewer satellites than planned and a weaker positioning solution. Every point to be GPS surveyed must be inspected for such obstructions and the obstructions must be properly mapped. The observation planning software should be updated with these obstructions to provide better session planning and, eventually, better results. Generally, some GPS obstructions can be tolerated to the north of the station due to the orientation of the satellite orbital planes coming into view in the south. The second types of obstructions are those that do not completely block the signal but may hamper integer fixing, such as tree canopy. If the location of the point cannot be altered, longer observation sessions are required to assure quality results.
- **Interference** – Electromagnetic signal interference can cause lower  $C/N_0$  values and less reliable observations. Areas with very high wireless communication traffic or nearby high voltage power lines should be avoided. Longer sessions could overcome some of the effect of the interference.

#### 4. Operation Errors

- **Satellite Geometry** – There are several satellite geometry factors to be considered when planning a GPS survey. These factors influence the geometry of the satellites in space at the time of observations is an important factor of GPS positioning accuracy. These factors include the number of satellites available, the minimum elevation angle for the satellites (elevation mask), obstructions that limit satellite visibility, and the various locations of each satellite with respect to the receiver. The best geometry is when the satellites are evenly distributed around the horizon and at least one satellite is at the zenith. The worst geometry is when all the satellites are bunched together in a small region of the sky.

## 5. Data Processing Errors

Data processing errors are those errors which can be identified only when the field work has been completed. During the processing of the field data certain “poor” observations have to be filtered while others can be corrected with the software.

- **Loop Closures** – Closed loops of baselines are used for the quality control of the measurements and their respective errors in a similar way as used in traversing and leveling. A loop is defined as a series of at least three independent, connecting baselines, which start and end at the same station. Each loop shall contain baselines collected from a minimum of two independent sessions. The acceptable closure for a given survey task should be specified at its planning stage. Survey tasks that require higher accuracies will have more stringent acceptable closures and vice versa.
- **Ambiguity Resolution Error** – The ambiguity in GPS surveys is an integer number of full carrier wave cycles between the receiver and the satellite. An inaccurate ambiguity determination results in a position error because the computed distance between the



receiver and the satellite is incorrect. This value cannot be measured directly, but must be computed (resolved) using sophisticated algorithms. Longer sessions and low GDOP values will reduce the potential for ambiguity resolution errors.

- **Cycle Slip** – A cycle slip is a discontinuity in GPS carrier phase observations caused by signal loss, usually due to obstructions. If a GPS receiver loses a signal temporarily, when the signal is reacquired there may be a jump in integer number of full carrier phase cycles (ambiguity). This jump must be identified and corrected; otherwise the position determination may be in error. Most GPS software have cycle slip repair tool to correct short cycle slips. If the cycle slip cannot be repaired, some of the observations may have to be discarded.
- **Station Coordinate and Transformation Errors** – Since GPS surveys are made relative to known control points, an error in the coordinate values of these control points will translate into errors in the newly determined points. The same applies to elevations and benchmarks. This error can be detected if a GPS survey is tied into several control points. Erroneous coordinate or elevation values will result in an inconsistent fit between the survey and the control points.

Dilution of Precision (DOP) is a purely geometrical contribution to the uncertainty in a position fix. It is a unit-less number that indicates the error in position determination as a function of the relative satellite geometry. GPS derived positions uses four parameters: position ( $X, Y, Z$ ) and time  $t$ . The DOP for all four parameters is called Geometric DOP (GDOP). The DOP for a three coordinate position ( $X, Y, Z$ ) is called PDOP, the DOP for two horizontal coordinates ( $X, Y$ ) is called the HDOP, and for vertical position only is called the VDOP. For surveys, it is recommended to use GDOP as the indicator for favorable observation geometry. Observations should be done at times when the GDOP is less than

4. One should never perform GPS surveys when GDOP is more than 8.

GDOP information is computed by an observation planning software. It is based on the predicted location of the satellites relative to the observer. One should be aware of two factors which may change the actual value of GDOP at the time of observation. These factors are obstructions blocking the satellite signals and unanticipated operational problem of satellites. If obstructions are not mapped properly, the software assumes that all the satellites are visible and the computed GDOP may not reflect the actual situation. Similarly, if the observation sessions are planned in advance and one of the satellites has since stopped operating properly (or temporarily turned off), the actual GDOP at the time of observation may not be the same as predicted. Always check the actual GDOP, as indicated on the receiver, to ensure quality observations.

- **Length of Session** – The length of a session is the maximum time interval at which data is collected from all the receivers simultaneously. This means that it is not enough to collect data at a point, but this data collection must be coordinated with other receivers. Longer sessions can provide better results, but are more expensive. The length of a particular session depends on the type of receivers used, the length of the measured baseline, project specifications etc. One should consult the user's manual of the receiver for determining the optimal length of an observation session.
- **Instrument Setup** – The GPS antenna must be placed directly above the point on the ground with the same attention to detail as in any other survey. A setup error translates directly into a position error. See the total station setup procedure in this manual for details on how to minimize setup errors.
- **Antenna Height** – One of the most common errors in GPS surveys is the incorrect reading or recording of the height of the antenna. Antenna height error affects all three position parameters ( $X$ ,  $Y$ ,

Z), but is more critical for elevation surveys. The height of the antenna should be measured for every setup at least twice, once before the first observation and immediately after the last observation. If the height of the antenna is measured manually, then it must be measured with two independent measuring systems (Metric/English) to eliminate blunders. This measurement is then reduced to the reference point (ARP). The use of a fixed-height 2-meter pole is highly recommended, thus eliminating the antenna measurement and the possibility of an incorrectly recorded height.