1 Introduction

**Note:** Partial solutions to problems marked with an asterisk are given in Appendix H.

**1.1** Describe the steps involved in accounting for the existence of errors in observations.

From Section 1.1, paragraph 4: “The steps involved in accounting for the existence of errors in observations consist of (1) performing statistical analyses of the observations to assess the magnitudes of their errors, and study their distributions to determine whether or not they are within acceptable tolerances; and if the observations are acceptable, (2) adjusting them so they conform to exact geometric conditions or other required constraints.”

**1.2** List two examples of direct measurements.

From Section 1.2, paragraph 1: “Determining the distance between two points by making a direct measurement using a graduated tape, or measuring an angle by making a direct observation from the graduated circle of a total station instrument are examples of direct measurements.”

**1.3** List two examples of indirect measurements.

From Section 1.2, paragraph 2: “For example, surveyors may observe angles and lengths of lines between points directly and use these observations to compute station coordinates. From these coordinate values, other distances and angles that were not observed directly may be derived indirectly by computation.”

**1.4** List four unconditional statements about measurements.

From Section 1.3, paragraph 1: “It can be stated unconditionally that (1) *no measurement is exact*, (2) *every measurement contains errors*, (3) *the true value of a measurement is never known, and thus* (4) *the exact size of the error present is always unknown*.”

**1.5** Define the sources of errors and provide an example of each.

From Section 1.3, paragraph 3:

“1. *Instrumental Errors.* These errors are caused by imperfections in instrument construction or adjustment. For example, the divisions on a theodolite or total station instrument may not be spaced uniformly.

2. *Natural Errors*. These errors are caused by changing conditions in the surrounding environment. These include variations in atmospheric pressure, temperature, wind, gravitational fields, and magnetic fields.

3. *Personal Errors*. These errors arise due to limitations in human senses, such as the ability to read a micrometer or to center a level bubble. The sizes of these errors are affected by personal ability to see and by manual dexterity.”

**1.6** State whether the following are mistakes, systematic errors, or random errors.

**(a)** Earth curvature and refraction. **Systematic**

**(b)** Imperfect centering over a point. **Random**

**\*(c)** Contraction of a tape due to a temperature other than standard. **Systematic**

**(d)** Recording a length of 135.48 as 135.44. **Mistake**

**(e)** Reading of the horizontal circle on a total station. **Random**

**1.7** Discuss the difference between a mistake and an error.

From Section 1.4, paragraph 1: *Mistakes* are caused by confusion or by an observer’s carelessness. They are not classified as errors and must be removed from any set of observations. Errors can be either systematic or random. *Systematic errors* follow some physical law, and thus these errors can be predicted. Some systematic errors are removed by following correct observational procedures. *Random errors* are the errors that remain after all mistakes and systematic errors have been removed from the observed values. In general, they are the result of human and instrument imperfections. They are generally small and are as likely to be negative as positive. They usually do not follow any physical law and therefore must be dealt with according to the mathematical laws of probability.

**1.8** Give an example of (There are several examples for each part of the problem.)

**(a)** A random instrumental error.

Bubble not centered at the instant a level rod is read.

(b) A random natural error.

Temperature variations along a line of sight for an electronically measured distance.

(c) A random personal error.

Small errors in reading graduated scales.

**1.9** Define the term discrepancy.

From Section 1.5, paragraph 1: “A *discrepancy* is defined as the algebraic difference between two observations of the same quantity.”

**1.10** Identify each of the following errors as either systematic or random.

(a) Bubble not centered at the instance of reading a rod. **Random**

(b) A vertical circle indexing error on a total station. **Systematic**

\*(c) Use of a tape that is not of standard length. **Systematic**

(d) Reading the graduated horizontal circle on a total station. **Random**

**1.11** Define precision and accuracy.

From Section 1.5, paragraph 1: “Precision is the degree of consistency between observations and is based on the sizes of the discrepancies in a data set. Accuracy is the measure of the absolute nearness of an observed quantity to its true value.”

**1.12** Identify each of the following errors according to its source (natural, instrumental, personal):

**\*(a)** Level rod length. Instrumental

(b) EDM–reflector constant. Instrumental

(c) Air pressure in an EDM observation. **Natural**

(d) Reading a graduation on a level rod. **Personal**

(e) Earth curvature in leveling observations. **Natural**

(f) An inclined line of sight in an automatic level. **Instrumental**

\***1.13** The calibrated length of a particular line is 199.998 m. A length of 200.001 m is obtained using an EDM. What is the error in the observation?

**ε = 0.003 m**

**1.14** In Problem 1.13 if the observed length is 199.996 m, what is the error in the observation?

**ε = −0.002 m**

**1.15** Why do surveyors measure angles using both faces of a total station (i.e., direct and reversed)?

To correct for instrumental, systematic errors in the instrument.

**1.16** List two examples of redundant observations in surveying.

From Section 1.6, paragraph 2 and 3: “Two measurements of the length of a line, for example, yield one redundant observation. … For example, there is one redundant observation when the three angles of a plane triangle are observed.”

**1.17** Discuss the importance of making redundant observations in surveying.

Allows someone to assess the discrepancy in the measurements and decide if a blunder may have occurred in the observation process.

**1.18** A line is observed as 156.58 ft, 156.60 ft, and 156.61 ft. How many redundant observations were observed?

**Two**

**1.19** Why do prudent surveyors always obtain redundant measurements?

From Section 1.6, paragraph 5: “Prudent surveyors always make redundant observations in their work, for the two important reasons indicated above: (1) to enable assessing errors and making decisions regarding acceptance or rejection of the observations, and (2) to make possible an adjustment whereby final values with higher precisions are determined for the unknowns.”

**1.20** What mathematical condition is enforced in a least squares adjustment?

From Section 1.7, paragraph 3: “As described later in the book, in a least squares adjustment, the following condition of mathematical probability is enforced: *The sum of the squares of the errors times their respective weights are minimized*.”

**1.21** List the advantages that the least squares method has over rule-of-thumb adjustment procedures.

From Section 1.7, paragraph 2: “The advantages of least squares over other methods can be summarized with the following four general statements; (1) it is the most rigorous of adjustments; (2) it can be applied with greater ease than other adjustments; (3) it enables rigorous post-adjustment analyses to be made and (4) it can be used to perform presurvey planning. These advantages are discussed further below.”