INDEX

χ² distribution, 59–61, 85–86, 637–638
χ² test, 85–89, 330, 568

Accuracy
  1998 FGDC standards, 435–440
definition of, 5
examples of, 5–6
local, 438
network, 436, 438, 440

Adjustment
  constrained, 63, 71, 89–90, 443, 468
  minimally constrained, 71–72, 89–90, 362–363, 468, 476
Adjustment of control coordinates, 443–449

Affine coordinate transformation, 395
general least squares method, 507

Alternative hypothesis, 79, 330

Angle
  error in astronomical observation, 130
  error in directional method, 115
  error in instrument centering, 120
  error in leveling, 123–124
  error in observation, 126
  error in pointing, 116
  error in reading, 114
  error in repetition method, 114
  error in target centering, 118
  error using range poles, 136
  error using total station, 117
  intersection adjustment, 288–293
Angle (continued)
ISO 17123-3 standard, 117
observation equation, 123, 286, 518, 522, 528
reading errors, 114–116
resection adjustment, 294–298
weight in, 185
Apogee, 347
APRS Accuracy Standards
for Digital Geospatial Data, 439
Astronomical observation, 130
Azimuth, 130, 146, 535, 666–667
Azimuth observation equation, 284, 521, 529
Baarda, Willem, 472
Back solution, 583
Baseline
adjustment of, 362–363, 552
analysis of, 356
analysis of repeat, 357–358
loop closure errors, 360
Bessel’s correction, 31–32
Bimodal distribution, 17–18
Bivariate distribution, 122, 419–420
Blunder
a priori methods, 466
definition of, 4
detection of, 49, 58, 465–466
example of, 477, 566
graphical methods, 467, 572
signs of residuals, 468, 565, 572
Carrier phase-shift observations, 344
Chi-squared distribution, 59–61, 85–86, 637–638
Chi-squared test, 85–89, 330, 568
Cholesky decomposition, 581
Class
frequency, 16
interval, 16
relative frequency, 16
width, 15–16
Class width
definition of, 15
example of, 15–16, 27
Cofactor, 179
Cofactor matrix
of adjusted observations, 249
of adjusted unknowns, 248–249
definition of, 180
elements, 249–250
of residuals, 470
Collimation error, 163
Compound event, 40–41
Conditional equation, 215–217
Confidence interval
definition of, 59
mean, 63–66, 649
population variance, 68–70
ratio of two population variances, 70–72
sample, 66–68
using STATS, 72–74
Conformal coordinate
transformation
general least squares method, 392, 503, 509
three-dimensional, 401–407, 509, 546–547
two-dimensional, 389–390, 392, 503–504
Constrained adjustment
definition of, 443
elimination of constraints method, 449
Helmert’s method, 452–453
least squares, 71, 89–90, 468
minimally, 71–72, 89–90, 362–363, 468
by over-weighting, 458–460
redundancies, 458
Constraint equation
control station coordinate
adjustment, 443
elimination of, 262, 449
Helmert’s method, 452–453
Constraints, geometric, 136, 193
Control coordinates
adjustment of, 443
estimating uncertainties in, 447
Control, minimum amount of, 321–322, 476
Conventional Terrestrial Pole (CTP), 348
Coordinate system
earth-centered, earth-fixed, 546
geocentric, 348
geodetic, 349, 518
local geodetic, 517
satellite, 348
Coordinate transformation
affine using general least squares method, 507
conformal using general least squares method, 392, 503, 509
eight parameter, 398–399, 508
four parameter similarity, 389–390
projective using general least squares method, 399, 507
seven-parameter similarity, 401–407, 509, 546–547
six parameter, 395, 507
three-dimensional conformal, 401–407, 509, 546–547
three-dimensional using general least squares method, 509, 546
two-dimensional affine, 395, 507
two-dimensional conformal, 389–390, 392, 503–504
two-dimensional projective, 398–399, 508
Covariance, 99, 179–180
Covariance matrix
of adjusted observations, 250–253
of adjusted unknowns, 249–250
definition of, 97–101, 248–249
development of, 97–101, 248–249
example of, 249
in traverse course, 145
Data
classes in, 15–16
graphical representation of, 15–18
population, 13–14
range of, 14–15, 24, 27
sample, 13–14
Data snooping, 472
Datum, 545
Deflection of vertical, 535
Degrees of freedom, 20
Density function, 42
Detectable blunder, 485
Determinant, 607
Differencing
double, 345
single, 345
triple, 345
Differential leveling
adjustment of, 226–231
collimation error in, 163–164
leveling errors in, 163–166
observation equation, 225
random errors in, 166–171
reading error in, 166–171
rod plumbing error in, 167–169
systematic errors in, 163–166,
536–537
in three-dimensional adjustment, 522
weights in, 186–187, 229
Discrepancy, 4
Dispersion, 14
Distance observation equation
definition of, 259
linearized, 261
Distribution
\( F \), 62–63, 641–648
normal, 17, 42, 193, 565–566, 629,
635–636
sampling, 59
\( t \), 61–62, 84, 639–640
\( X^2 \), 59–61, 85–86, 637–638
Double differencing, 345
Earth curvature and refraction error, 165, 522, 535
EDM calibration, 214–215
Eight parameter transformation. See Projective coordinate transformation
Elimination of constraints, 449
Ellipse
   analysis of, 431
   computation of, 425
Equation
   normal, 200, 201–204, 580–581
   observation, 199–200 (See also Observation equation)
   residual, 199–200, 231
Error
   in angular misclosure of traverse, 127–130, 146–148, 152–153
   in azimuth observations, 130, 146, 535
   in azimuths of traverses, 146
   collimation, 163
   definition of, 3, 19–20
   earth curvature and refraction, 165, 522, 535
   in electronic distance measurement, 135–136
   ellipse, 419
   GNSS, 347
   gross, 3
   instrumental, 3, 120
   in leveling, 163–166
   in linear misclosure of traverse, 146, 148–151, 153–154
   natural, 3
   personal, 3
   radial, 435
   random, 4, 21, 113–114, 135–136, 166–171, 565
   sources in angles, 113–114
   sources in electronic distance measurement, 135
   standard, 21–22
systematic, 4, 5–7, 115, 163–166, 534–537
   in traverse course, 144–145, 156
   in trigonometric leveling, 171–174
   in zenith angles, 172
Error ellipse
   advantages of, 409
   confidence level of, 429–431
   in network design, 431–435, 487
   overview, 419–421
Error propagation
   in angles, 126–127
   definition of, 2
   in distances, 135
   equation, 97–101, 245
   in leveling, 163–174
   in traverse surveys, 143
Estimator, 59
EXCEL®
   accompanying files, 219
   errors in traverse computations, 156
   estimating error in observations, 137
   spreadsheet use, 33, 674
External reliability, 486
F distribution, 62–63, 641–648
FGDC standards, 435–440
Fisher distribution, 62–63, 641–648
Fit of points to a line, 211–213
Fit of points to a parabola, 213–214
Forward solution, 583
Four-parameter similarity transformation. See Conformal coordinate transformation
Free network adjustment, 322
Frequency histogram, 15–18, 26, 52
Functional model, 197–198
General law of propagation of variances (GLOPOV), 100, 143, 250–251
General least squares method
- affine coordinate transformation, 507
- conformal coordinate transformation, 392, 503, 509
- projective coordinate transformation, 399, 507
- solution, 499–500
- for straight line, 497–499
- three-dimensional coordinate transformation, 509, 546

Geocentric coordinate system, 348

Geodetic height, 349, 523, 557

Geodetic network, three-dimensional adjustment of, 517, 537–538

Geoid separation, 523

Geometric constraints, 146, 193

Global navigation satellite system (GNSS)
- baselines, 346, 363, 366–367
- observations, 344–347
- overview, 257
- preanalysis of observations, 356

GLOPOV, 100, 143, 250–251

GNSS. See Global navigation satellite system (GNSS)

Goodness of fit test, 330, 568

GPS, 257, 343–344

Hour angle
- Greenwich, 130, 348
- local, 130

Hypothesis testing
- alternative hypothesis, 79, 330
- false negative, 82
- false positive, 82
- level of significance of, 81
- null hypothesis, 79, 330
- for the population mean, 84–85
- power of test, 81
- ratio of two variances, 89–92
- rejection criterion, 80–81
- test decision, 80
- test statistic, 79–80
- type I error, 80
- type II error, 80
- using STATS, 92–93
- for variance, 85–89

Indirect measurement, 2

Internal reliability, 485

Iteration, termination of, 273

Jacobian matrix, 100, 148, 208, 263, 294, 622

Keplarian parameters
- argument of perigee, 348
- eccentricity, 348
- Greenwich hour angle of the vernal point, 348
- inclination angle, 348
- right ascension of the ascending node, 348
- semimajor axis, 348

Lambert Conformal Conic
- as map projection system, 656
- mathematics of, 657–659
- reduction of distances, 664
- reduction of geodetic azimuths, 666
Lambert Conformal Conic

(continued)

reduction of observations, 663
stereographic, 662
Transverse Mercator, 656, 659

Law of cosines, 123

Least squares
adjustment of angles, 283
adjustment of distances, 257
adjustment of horizontal networks, 313
adjustment of intersections, 288
adjustment of resections, 293
advantages of, 8–10
affine coordinate transformation, 507
analysis of, 432, 465, 566
angle intersection, 432, 465, 566–567
conditional adjustment, 198, 215–216
conditional adjustment model of, 198
conformal coordinate transformation, 392, 503, 509
constrained, 71, 89–90, 468
differential leveling adjustment, 225
fit of points to a line, 211–212, 500
fit of points to a parabola, 213–214
fundamental principle, 194–197
generalized method, 497–503
minimally constrained, 71, 89–90, 468
parametric adjustment model of, 198
projective coordinate transformation, 399, 507
simulated adjustment, 488
stochastic model in, 197
three-dimensional coordinate transformation, 509, 546
three-dimensional geodetic network, 517

Line of apsides, 347
Link traverse misclosure error, 152–156
Local accuracy, 438
Localization, 390, 551

Map projection coordinate systems
coordinate transformation and, 556–559
horizontal surveys and, 257–258
Lambert Conformal Conic, 656, 657–659
oblique stereographic, 556, 662
overview, 655–656
reduction of distances, 664–666
reduction of geodetic azimuths, 666–667
reduction of observations, 663–667
stereographic, 662–663
Transverse Mercator, 656, 659–662

Mapping standards, 28–31
MATHCAD®
files in, 219, 276, 288, 324, 367, 394, 490, 537
map projections in, 659, 663
statistical functions in, 33, 490

Matrix
addition, 595
Cholesky decomposition of, 581
cofactor, 180, 248–249, 251
column, 593
covariance, 99, 145, 179, 248, 251–252
definition of, 591
determinant of, 607
diagonal, 594
dimensions of, 592
elementary row transformations, 611
equality, 594
equivalent weight, 499
inverse of, 607
Jacobian, 100, 148, 208, 263, 294, 622
multiplication, 595
partitioning of, 253
row, 593
scalar multiplication of, 595
size of, 592
solution of equations, 607
square, 593
symmetric, 594
transpose of, 594
types of, 593
unit, 594
vector, 593
weight, 180, 207, 365–366, 499

Matrix algebra, 591
Matrix operations, computer
  algorithms of, 577–589, 598, 615

MATRIX software
  differential leveling, 236
  horizontal network, 318
  triangulation, 297
  trilateration, 269, 274
  using, 33

Mean
  arithmetic, 5, 19
  confidence interval, 63–66, 649
  example of, 19, 24, 26
  population, 19, 84–85
  sample, 19
  standard deviation of, 22, 102, 182
  weighted, 181–183

Measure of central tendency
  definition of, 18–19
  mean, 19
  median, 19
  mode, 19

Measurements, direct and indirect, 2

Median
  definition of, 15, 19
  example of, 24

Minimally constrained adjustment, 71–72, 89–90, 362–363, 468, 476

Misclosure in traverse, 146–151, 152–156

Mistakes, 3–4

Mode
  definition of, 19
  example of, 24, 27

Model
  functional, 197–198
  mathematical, 198–199
  stochastic, 197

Most probable value, 20

NAVSTAR GPS, 343

Network
  adjustment of, 322
  definition of, 322
  design of, 431–435, 487
  GNSS baseline, 346, 363, 366–367
  leveling, 226

Noncentrality parameter, 485

Nonlinear equations
  angle, 286
  azimuth, 284
  distance, 260
  linearized, 261, 287, 314
  solution of, 619

Normal
  distribution, 17, 193, 565–566, 629, 635–636
  distribution curve, 42, 629
  distribution function, 44, 629, 635–636
  radius of, 351

Normal equation
  definition of, 200
  direct formation, 580–581
  systematic formulation of, 201–203
  tabulation formation, 203–204

Normal matrix
  definition of, 205
  direct formation of, 204–207, 268, 580–581
Null hypothesis
definition of, 79
failure to reject, 80–81, 330

Observation
analysis of, 13–19, 432, 465–466, 565
measurements and, 2, 18
nonspur, 474–475
population, 13–14
propagation, 2
redundant, 7–8, 20, 232, 458
sample, 13–14
spur, 474–475

Observation equation
altitude angle, 123, 518, 522
angles, 123, 286, 518, 522, 528
azimuth, 284, 521, 529
baseline vector, 363, 552
control station coordinates, 443, 530
definition of, 199
differential leveling, 225, 522
distance, 259, 519, 523, 525, 527
horizontal angle, 286, 522, 528
horizontal distance, 260, 523–524
horizontal network, 314, 322
overview, 199–200
projective coordinate
transformation, 398–399, 507–508
slant distance, 519, 527
three-dimensional conformal
coordinate transformation, 404, 509
two-dimensional affine coordinate
transformation, 395, 507
two-dimensional conformal
coordinate transformation, 392, 504
two-dimensional coordinate
transformation, 389–390, 392, 503
two-dimensional projective
coordinate transformation, 398–399, 508
vertical plane, 522

Orthometric height, 349, 522, 557

PDOP (Positional dilution of precision), 433, 488
Perigee, 347–348
Pope, Alan J., 474
Population, 13–14
Population variance, 20, 85–86, 330

Positional dilution of precision (PDOP), 433, 488
Precision, 4–6

Probability
computation of, 44–49
curve, 42, 629
standard error, 21–22, 47
theory of, 39
Probability curve, 42, 629
Probability density function, 42, 629

Probable error
50%, 48
95%, 49
other values, 49
uses of, 50–52

Projective coordinate
transformation, 398–399, 507–508
general least squares method, 399, 507

Propagation of variance
general law, 100
special law, 101

Prototype equation
angles, 522
azimuths, 286, 314, 521
baseline vector, 363
for differential leveling, 225
for distances, 261, 314, 523–524
horizontal angles, 258, 314, 522
horizontal network, 314
slant distances, 519
Pseudorandom noise codes, 344
Pseudoranging, 344

Radial error, 435
Random error
  in angles, 113–114
  definition of, 4
  in electronic distance
    measurements, 135–136
  in leveling, 166–171
  properties of, 4, 21, 565
Range
  definition of, 14
  example of, 14–15, 24, 27
  in GNSS, 344
Redundancy number
  definition of, 472
  effects in blunder detection, 485
  relative, 472
Redundant observations, 7–8, 20, 232, 314
Reference frames, 545–546
Rejection criterion, 80, 472–473
Relative positioning, 346
Relative redundancy, 472
Reliability
  external, 486
  internal, 485
Reordering algorithms, 587
Resection, adjustment of, 293
Residuals
  analysis of, 465–466, 565–568
  cofactor matrix of, 470
  computation of, 24–25
  definition of, 20
  equation, 199–200, 231
  equivalent, 499
  properties of, 565
  signs of, 468, 565, 572
  standardized, 472
  use of plots, 572
Root mean square error (RMSE), 27–31, 439

Sample
  definition of, 13–14
  selecting size of, 67–68
Sample variance, 21
Sampling distribution, 59
Satellite system
  GPS, 257, 343–344
  TRANSIT, 343
Seven-parameter similarity
  transformation.  See
    Three-dimensional conformal
    coordinate transformation
Single differencing, 345
Site calibration.  See Localization
Six parameters transformation.  
  See Affine coordinate
  transformation
Slant distance, 519
Sparseness in matrix, 586
Special law of propagation of
  variance (SLOPOV), 101, 143
Spreadsheets, use of, 33, 674
Standard deviation
  definition of, 22
  example of, 24–25
  of the mean, 22, 102
  modified for weighted
    observations, 184
  reference, 231–232, 249
  in series, 102
  in sum, 102
  of unit weight, 181, 231–232, 249
  of weighted mean, 182
Standard error
  definition of, 22, 31
Standard error (continued)
probability of, 47
relation to weight, 183
of weight $w$, 184–185
Standard error ellipse, 421
Standard error rectangle, 419
Standardized residual, 472
Statistic, definition of, 18
Statistical test
$F$, 89
goodness-of-fit, 330
one-tailed, 83
for population mean, 84
for population variance, 85–86, 330
for ratio of two variances, 89
t, 84
two-tailed, 83
$\chi^2$, 85–89, 330, 568
STATS
certainty intervals, 72–74
histogram data, 32–33
hypothesis testing, 92–93
Stochastic model, 197
Storage optimization, 586
Survey planning and design, 157, 431–432, 487
Systematic error
in azimuths, 535
definition of, 4
examples of, 4, 5–7
in leveling, 163–166, 536–537
in vertical angles, 535

t distribution, 61–62, 84, 639–640
Table
confidence intervals, 650–654
$F$ distribution, 642–648
standard normal distribution, 635–636
t distribution, 640
$\chi^2$, 638
Tabular method, 203

Tau criterion, 474
Taylor’s theorem
nonlinear equations and, 619–620
use of, 207–208, 260, 285, 287
Test decision, 80
Test statistics, 79–80
Three-dimensional conformal
cordinate transformation, 401–407, 509, 546–547
general least squares method, 509, 546
Three-dimensional geodetic network
adjustment, 517, 537–538
Transformation between reference
frames, 545–546
TRANSIT, 343
Traverse
error in angular misclosure, 127–130, 146–148, 152–153
error in latitude and departure, 144–145
error in linear misclosure, 146, 148–151, 153–154
estimating errors using EXCEL®, 156
misclosure in, 127–130, 146–156
Triangulation adjustment, 283
Trigonometric leveling, error in, 171–174
Trilateration adjustment, 257
Triple differencing, 345
True value, definition of, 19
Two-dimensional
affine coordinate transformation, 395, 507
conformal coordinate
cordinate transformation, 389–390, 392, 503–504
projective coordinate
cordinate transformation, 398–399, 508
Type I error, 80
Type II error, 80
Valid parameters, 407–411
Variance
  alternative formula for, 22–24
  definition of, 20
  example of, 27
  population, 20, 85–86, 330
  reference, 180, 330
  sample, 21
  of unit weight, 181, 231–232, 249, 330
Vertical, deflection of, 535
Weight
  in angles, 185
  definition of, 179
  in differential leveling, 186–187
  relation to correction, 183
  relation to standard error, 183
  relation to variance, 179, 183
Weight matrix, equivalent, 180, 499
Weighted mean, 181–183