Index

Categorical regressors, 450

Cause-and-effect, 333

А

Acceptance region, 280, 290 Actual process capability versus potential process capability, 622 Addition of center points to 2^k factorial, see Center points in 2^k factorial design Addition rules of probability, 33, 24 Adjusted R², 431 All possible regressions, 453 Alternate fraction 551 Alternative hypothesis, 279 Analysis of variance, 387, 421, 429, 469, 473, 475, 493, 494, 495, 13-5, 506, 511, 589 Analysis of variance method for estimating variance components, see Estimating variance components Analytic study, 5, 7 Anderson-Darling statistic, 6-1 ANOVA partition of total sum of squares, 474 Approximations to distributions, 119: Continuity corrections, 4-1 Normal approximation to binomial, 120, 310 Normal approximation to Poisson, 121 Assignable cause of variation, 598 Asymptotic relative efficiency, 584 Attributes control charts, 601, 625 Average run length, 630 Axioms of probability, 30, 31

В

Backward elimination of variables in regression, 459 Basic design, 552 Bayes estimation of parameters, 7-3 Bayes estimator, 7-4 Bayes' theorem, 51, 52 Bernoulli random variable, 11-7 Bernoulli trial, 72 Bias in estimation, 223 Bias of estimator, 223, 226 Binomial distribution, 74, 87, 119, 120, 155, 310, 9-3.9-4 Binomial random variable, 74, 76, 84, 573 Bins (cells) in histogram, 203, 204 Bivariate distribution, 143, 177 Bivariate normal distribution, 177, 178, 401 Block effect, 493 Blocking, 492, 496, 543, 545 Blocking as restriction on randomization, 496 Bootstrap, 7-2 Bootstrap confidence interval, 8-1 Bootstrap estimate of standard error, 7-2 Bootstrap sample, 7-2, 8-1 Box plot, 207, 208, 471

Cause-and-effect diagram, 598, 640 Censored data, 246, 275 Center line on control chart, 10, 599, 600 Center points in 2^k factorial design, 541, 14-9, 14-10 Central composite design, 14-16, 14-17 Central limit theorem, 109, 240 Chance cause of variation, 598 Chebyshev's inequality, 5-13, 5-14 Check sheet, 598 Chi distribution, 7-1 Chi-square distribution, 133, 7-1, 262, 308 Chi-square distribution percentage points, table of, 655 Chi-square tests, 307, 316, 321 Choice of sample size and confidence intervals, 252, 260, 266, 267, 335 Choice of sample size for single-factor experiments, 482, 484, 490, 13-7, 13-11 Choice of sample size in statistical tests, 293, 294, 295, 297, 304, 305, 309, 312, 314, 331, 344, 359, 364 Coding data, 219 Coefficient of determination, 397; also see R² Combinations, 2-3 Common cause of variation, 598 Comparative box plots, 208 Comparative experiments, 278, 328 Comparison of nonparametric tests to t-test, 579, 584, 588 Complement (set operation), 23 Completely randomized design, 333, 472 Complications in maximum likelihood estimation 235 Components of variance, 473, 487, 488, 489, 14-4 Components of variance model, see Random effects model ANOVA Conceptual population, 190 Conditional mean, 147, 163 Conditional probability, 37, 38, 51, 125, 126 Conditional probability density function, 162 Conditional probability distribution, 146, 153, 162, 169, 5-2 Conditional probability mass function, 146. 153 Conditional variance, 147, 163 Confidence coefficient, 250 Confidence interval, 247, 248, 250, 253, 254, 256, 258, 259, 263, 266, 334, 345, 346, 365, 390, 391, 403, 437, 477, 478

Confidence interval on correlation coefficient, 403

Confounding, 543, 544, 546, 548 Connection between confidence intervals and hypothesis tests, 293 Connection between gamma and chi-square distributions, 133 Connection between Poisson and Erlang distributions, 129 Connection between Poisson and exponential distributions, 123 Connection between Weibull and exponential distributions, 134 Consistent estimator, 245 Contingency table, 320, 322 Continuity corrections, 4-1 Continuous probability distribution, 98: Chi-square, 133 Erlang, 130 Exponential, 123 F, 355, 356, 357, 10-1 Gamma, 131, 132 Lognormal, 136 Normal, 109, 110, 119, 120, 121, 204, 240 t, 258, 8-2, 301 Uniform, 107 Weibull 134 Continuous random variable, 54, 97, 98, 100, 157, 5-3, 5-4 Continuous sample space, 19 Continuous uniform distribution, 107

Confidence interval on difference in means of

Confidence interval on difference in two treatment

Confidence interval on mean response, 390, 438

Confidence interval on ratio of variances of two

Confidence interval on regression coefficients,

Confidence interval on variance of normal

Confidence interval on treatment mean in ANOVA

Confidence level and precision of estimation, 251

Confidence interval on population proportion,

two normal distributions:

Confidence interval on difference in two

Confidence interval on mean of normal

Variance known, 249, 250, 253

Variance unknown, 257, 259

normal distributions, 359

distribution, 261, 263

Variances known, 334 Variances unknown, 345, 346

proportions, 365

distribution.

265 266

389 437

477.478

means in ANOVA, 478

704 INDEX

Continuous uniform random variable, 107 Contour plot, 411 Contrasts, 13-2, 525, 526, 532 Control chart, 10, 598, 599, 600, 601, 602, 607, 609, 610, 615, 625, 627, 632 Control chart for defects per unit, see U-chart Control chart for fraction defective, see P-chart Control charts and hypothesis testing, 599 Controllable variables, 469 Convolution, 5-6 Cook's distance measure, 445 Correlation, 171, 174, 179, 352, 400 Correlation coefficient, 401 Covariance, 171, 172, 174, 182 Covariance matrix, 421 C_p statistic in regression, 454 Critical region, 280, 290 Cumulative distribution function, 63, 64, 102 Cumulative frequency plot, 205 Cumulative standard normal distribution, 653, 654 Cumulative sum control chart, 632, 634, 635 Cyclic data, 210

D

Data collection, 5 Data versus information, 6 Decision interval for CUSUM, 635 Defect concentration diagram, 598, 641 Defects 627 Defining contrast for blocking in 2^k factorial, 545 Defining relation for $2^{k_{21}}$ fractional factorial design, 550 Defining relation for 2^{k22} fractional factorial design, 556 Degree of belief interpretation of probability, 28 Degrees of freedom, 193 Deming's 14 points, 642 Dependent variable, see Response variable Design generator, 549, 556 Design resolution, 555 Designed experiment, 5, 6, 7, 11-1, 469, 506, 641 Designed experiments in engineering design, 470, 14-3 Digidot plot, 210, 211 Discrete probability distribution, 61: Binomial, 74, 87, 119, 120, 155, 310, 9-3, 9-4 Geometric, 78 Hypergeometric, 84, 87, 10-3 Negative binomial, 78, 80 Poisson, 89, 90, 119, 123, 129 Uniform, 70 Discrete random variable, 54, 59, 60, 62, 142, 143, 5-1 Discrete sample space, 19, 27 Discrete uniform distribution, 70 Discrete uniform random variable, 70 Distribution-free statistical methods, see Nonparametric statistics Dot diagram, 3, 8, 197

Empirical model, 11, 12, 373, 374; also see Regression model Engineering method, 2 Enumerative study, 5 Equal variance assumption in pooled t-test, 10-1 Erlang distribution, 130 Erlang random variable, 129, 131 a-Error, 281, 285 b-Error, 282, 285, 293, 309, 312 Error sum of squares, 379, 421, 429, 449, 474, 475, 488, 493; also see Residual sum of squares Estimated standard error, 225, 384 Estimating interaction in 2^k factorial, 525, 530, 531, 532

Estimating main effects in 2^k factorial, 525, 530, 531 Estimating variance components, 489 Estimation of parameters, 220; also see Point estimation of parameters, Parameter estimation Events, 22 EWMA control chart, 647 Exhaustive, 44, 52 Expectation function, 12-6 Expected mean squares, 474, 475, 488, 494, 13-6, 13-16, 513, 14-4, 14-7 Expected value of continuous random variable, 105 Expected value of discrete random variable, 66 Expected value of function of continuous random variable, 106 Expected value of function of discrete random variable 69 Expected value (mean) of linear combination of random variables, 181 Experimental design, see Designed experiments Experimental unit, 492 Exponential distribution, 123 Exponential probability plot, 6-2 Exponential random variable, 123, 125 Extra sum of squares method, 433, 12-1 Extrapolation and regression, 11-1, 440

2² Factorial design, 524 23 Factorial design, 530 2^k Factorial design, 1-3, 523, 529 Factorial experiment or design, 1-1, 1-3, 7, 506, 508 510 Factors for constructing tolerance intervals, 674, 675 Factors for constructing variables control charts, 673 Failure mechanism, 213 False alarm on control chart, 630 F-distribution, 355, 356, 357, 10-1 F-distribution percentage points, table of, 657, 658, 659, 60, 661 First (or lower) quartile, 200 First-order model, 14-12, 14-13 Fisher's LSD procedure, 479, 497, 516 Fisher-Irwin test, 10-3, 10-4 Fixed factor effects, 473, 511 Fixed-effects model ANOVA, 473 Forward selection of variables in regression, 458 2^{k21} Fractional factorial design, 549, 552 2^{k22} Fractional factorial design, 556 2^{k2p} Fractional factorial design, 555, 559 Fractional factorial experiment, 1-3, 549 Frequency distribution, 203 Full model, 434, 12-1 Functions of random variables, 5-1

G

Gamma distribution, 131, 132 Gamma function, 131, 7-1 Gamma random variable, 131, 132 Gauss-Newton method, 12-8 Gaussian distribution, 109; also see Normal distribution General method for deriving confidence interval, 253 General procedure for hypothesis testing, 287, 298 General regression significance test, see Extra sum of squares method Generalized interaction, 547 Generator of fractional factorial, see Design generator Geometric distribution, 78 Geometric or 61 notation for factorials, 524 Geometric random variable, 79 Goodness-of-fit measure, 6-1

Goodness-of-fit test, 315 Graphical comparison of means following ANOVA, 13-1

Н

Hat matrix, 443 Histogram, 203, 204, 598, 619 Hypergeometric distribution, 84, 87, 10-3 Hypergeometric random variable, 86, 87 Hypothesis, 7, 277, 278, 286 Hypothesis testing, 7, 221, 278, 280, 287, 289, 307, 310, 315, 320, 9-3, 329, 330, 331, 337, 338, 339, 341, 342, 357, 358, 359, 361, 362, 364, 10-3, 384, 387, 402, 428, 433, 572, 581, 585; *also see* Analysis of variance Hypothesis testing on correlation coefficient, 402 Hypothesis testing on difference in means of two normal distributions. Variance known, 329, 330, 331 Variance unknown, 337, 338, 339, 341, 342 Hypothesis testing on mean of normal distribution: Variance known, 289, 290, 291 Variance unknown, 300, 301, 303 Hypothesis testing on population proportion: Large-sample test, 310 Small-sample test, 9-3 Hypothesis testing on ratio of variances of two normal distributions, 357, 358 Hypothesis testing on regression coefficients in multiple linear regression: Extra sum of squares method, 433 Significance of regression, 428 Tests on individual regression coefficients, 432 Hypothesis testing on regression coefficients in simple linear regression, 384: Analysis of variance approach 387 Significance of regression, 385 t-Tests, 384 Hypothesis testing on variance of normal distribution, 307 Hypothesis testing on two population proportions: Large-sample test, 361, 362

I

Identity element, 533 In-control process, 598 Independence, 46, 47, 148, 170 Independent events, 47, 48 Independent random variables, 147, 148, 153, 164, 170, 182, 5-5, 197 Independent variable, see Regressor variable Indicator variables, 450 Individuals control charts, 615 Influential observations in regression, 444, 445 Interaction, 1-2, 412, 507, 508 Interpretation of confidence interval, 250, 251 Interquartile range, 201 Intersection (set operation), 23 Intrinsically linear model, 400 Invariance property of maximum likelihood estimators 235

Small-sample test, 364, 10-3

I

Jacobian of transformation, 5-3, 5-4, 8-3, 10-2 Joint probability density function, 157, 167 Joint probability distribution, 142, 145, 151, 167, 169, 172, 7-3 Joint probability mass function, 143, 151

Kruskal-Wallis test, 589, 590

705 INDEX

Lack of memory property of exponential random variable, 125, 126, 140 Lack of memory property of geometric random variable, 79, 80 Lack-of-fit sum of squares, 11-2 Large-sample confidence interval, 255 Large-sample confidence interval for mean, 254, 255 Large-sample hypothesis test on mean of normal distribution, 297 Least significance difference method, 479, 480, 497 Least squares estimator, see Method of least squares Least squares normal equations, 376, 409, 414, 417 Leverage in regression, 447 Likelihood function, 230 Likelihood ratio principle, 9-1 Likelihood ratio test statistic, 9-1 Linear combinations of random variables, 180, 181 Linear model, 374, 413, 417, 447, 12-5, 472, 492 Linear statistical model, see Linear model Location, 3 Logistic regression model, 11-6 Logit response function, 11-8 Lognormal distribution, 136 Lognormal random variable, 136 Lower confidence limit, 250 Lower control limit, 10, 599

М

Main effect, 507 Marginal probability density function, 159, 168 Marginal probability distribution, 144, 159, 168, 179, 7-3 Marginal probability mass function, 145, 152 Matrix of scatter plots, 416, 456 Maximum likelihood estimation, 230, 231, 233, 7-5, 9-1, 401, 11-8 Mean, 66, 105, 191 Mean of continuous random variable, 105 Mean of discrete random variable, 66 Mean of population, 191 Mean square error of estimator, 226 Mean squares, 387, 474, 475 Mechanistic model, 11 Median, 200, 205, 206, 572 Method of least squares, 376, 409, 414, 417 Method of maximum likelihood, 6-1; also see Maximum likelihood estimation Method of moments, 229 Method of steepest ascent, 14-13 Minimum variance unbiased estimator, 224, 234 Mixed model, 518, 14-6 Mode, 200, 205, 206 Model adequacy checking, 395, 441, 481, 498, 517, 527, 536, 554 Model building in regression, see Variable selection in regression models Moment estimator, 229 Moment generating function, 5-8, 5-9, 5-11 Moments about origin, 5-8 Moments of random variable, 5-8; also see Population moment Moving range, 616 Moving range control chart, 616 Multicollinearity, 460 Multinomial distribution, 75 Multinomial probability distribution, 154, 155 Multiple comparisons following ANOVA, 479, 497, 13-1, 13-2, 13-4, 516 Multiple linear regression model, 411 Multiplication rule for probabilities, 42, 43, 2-1 Multivariate data, 206 Mutually exclusive events, 24, 34, 35, 52

Natural tolerance limits of process, 621 Negative binomial distribution, 78, 80 Negative binomial random variable, 81, 82 Noncentral F distribution, 484 Noncentral t distribution, 304 Nonlinear regression model, 12-5, 12-7 Nonparametric statistics, 275, 572, 581, 585, 589 Nonparametric tolerance interval, 275 Normal (large sample) approximation in sign test 576 Normal (large sample) approximation in Wilcoxon rank-sum test, 587 Normal (large sample) approximation in Wilcoxon signed-rank test, 583 Normal approximation to binomial, 120, 310, 9-3 Normal approximation to Poisson, 121 Normal distribution, 109, 110, 119, 120, 121, 204, 240 Normal probability plot, 213, 214, 215, 6-1, 302, 395, 442, 481, 537 Normal probability plot of effects, 537, 539, 540 554 Normal probability plot of residuals, 395, 442, 481 Normal random variable, 110 NP-chart, 626 Nuisance factor, 492 Null hypothesis, 279

0

Objective view of probabilities, 7-3 Observational study, 5, 6 Odds ratio, 11-8 One observation per cell in two-factor factorial, 517 One-factor-at-a-time experiment, 508 One-half fraction, 1-3, 545 One-quarter fraction, 556 One-sample confidence intervals, 247, 248, 250, 253, 254, 256, 258, 259, 263, 266 One-sample hypothesis tests, 7, 278, 289, 297, 300, 301, 305, 307, 310, 312, 315, 320 One-sample t-test, 301 One-sample z-test, 290 One-sided alternative hypothesis, 279, 286, 291 One-sided confidence bounds, 253, 259, 264, 267 One-sided confidence bounds, 335 Operating characteristic curves, 295, 304, 309, 331, 344, 359, 482, 13-7 Operating characteristic curves for chi-square test, 666, 667, 668 Operating characteristic curves for F-test, 669, 670 Operating characteristic curves for t-test, 664, 665 Operating characteristic curves for z-test, 662, 663 Optimization experiment, 14-2, 14-11 Order statistics, 245 Ordered stem-and-leaf display, 200 Orthogonal contrasts, 13-2 Orthogonal design, 533 Outlier, 207, 396 Out-of-control process, 598 Overcontrol 8 Overfitting in regression models, 432

Paired samples, 349, 350, 576 Paired t-test, 349, 350, 491 Paired versus unpaired comparison of means, 351 Parameter estimation, 221, 222, 229, 230, 231, 234, 7-3, 376 Parameter estimation in nonlinear regression model, 12-7 Parametric statistical methods, 572 Pareto chart, 206, 207, 598, 639

Partial F-test, 434, 435 Partial regression coefficients, 411 Patterns on control charts, 599, 604, 605 P-chart, 625, 626 Percentile, 201 Permutations, 2-1 Pivotal quantity for constructing confidence interval, 253 Point estimate, 221 Point estimation of parameters, 220, 221, 229, 230, 231, 234, 7-3 Point estimator, 221 Poisson distribution, 89, 90, 119, 123, 129 Poisson process, 90, 123, 129, 130 Poisson random variable, 93 Polynomial regression models, 412, 447 Pooled estimator of variance, 338 Pooled t-test, 339, 10-1 Population, 190, 195, 221 Population moment, 229 Population standard deviation, 193 Posterior distribution, 7-3 Power of statistical test, 285 Precision of estimation, 225, 252 Prediction interval, 247, 249, 268, 393, 439 Prediction interval in regression, 393, 439 Prediction interval on future observation from normal distribution, 269 Prediction of new observations in regression, 392, 439 Predictor variable, 375; also see Regressor variable Principal block, 545 Principal fraction, 551 Prior distribution, 7-3 Probabilistic linear model, 374; also see Linear model Probability, 14, 27, 28, 29, 37, 42, 99 Probability density function, 98, 99 Probability distribution, 59, 61, 66, 70, 74, 78, 80, 84, 90, 97, 98, 142 Probability mass function, 61, 62, 90, 143, 145 Probability model, 14, 212 Probability plots, 212, 213, 6-1, 6-2, 315 Process capability, 619, 621, 622 Process capability ratio, 621, 622, 623 Process capability study, 601 Process characterization experiment, 14-1 Projection of fractional factorials, 554 Properties of estimators, 221, 225, 226, 245 Properties of least squares estimators, 383 Properties of maximum likelihood estimator, 234, 235 Pure error sum of squares, 11-2 *P*-value, 292, 299, 303 Quality improvement, 596 Quartiles, 200

R

R chart, 609 R^2 , 397, 398, 431 Random, 17 Random effect or factor, 518, 522 Random effects model ANOVA, 473, 487, 488, 518, 14-3, 14-4, 14-5 Random experiments, 17, 18 Random order of trials in experiment, 511 Random sample, 39, 40, 196, 225 Random variable, 3, 53: Continuous, 54, 96 Discrete, 54, 70 Randomization, 469, 471

706 INDEX

Randomized complete block design, 491, 13-16 Range, 194, 607 Rank transformation, 591 Ranks, 572, 581, 586, 589, 591 Rational subgroups and control charts, 602 Reduced model, 434, 12-1 Reference distribution, 301, 311 Reference value for CUSUM, 635 Regression analysis, 373 Regression and causality, 11-1 Regression coefficients, 374 Regression model, 13, 374, 411, 527 Regression model summary of 2^k factorial, 527 Regression sum of squares, 387, 429 Regressor variable, 375, 412, 450 Rejection region for statistical test *see* Critical region Relative efficiency in estimation, 227 Relative frequency, 28 Relative range, 607 Replicates, 1-1, 471, 510 Residual analysis, 395, 396, 11-1, 441, 442, 481, 498, 527, 536, 554 Residual plots, 481, 482, 498, 499, 517 Residual sum of squares, 11-2, 421 Residuals, 377, 395, 418, 441, 481, 517, 536 Resolution III design, 555, 562 Resolution IV design, 555, 556 Resolution V design, 555 Response surface, 14-12 Response surface methodology, 14-11 Response variable, 375, 412 Restricted model, 14-7 Retrospective study, 5 Ridge regression, 461, 12-2 Ridge trace, 12-2 Rotatable design 14-19 Runs rules, 607

S

S control chart, 610, 611 Sample, 20, 39, 40, 190, 196 Sample correlation coefficient, 402 Sample mean, 190, 197 Sample moment, 229 Sample range, 194, 607 Sample size formulas for confidence intervals, 252, 335 Sample size formulas for tests on proportion, 313 Sample size formulas for tests on means, 294, 332 Sample space, 18: Continuous, 19 Discrete, 19, 27 Sample standard deviation, 191, 197 Sample variance, 191, 192, 197 Sampling distribution, 221, 238, 289, 239 Sampling distribution of the mean, 239 Sampling with replacement, 20 Sampling without replacement, 20 Saturated fractional factorial design, 563 Scatter diagram, 373, 598 Scientific method, 2 Screening experiments, 470, 545 Second-order model, 14-10, 14-12 Sensitivity of a statistical test, 285 Sequential experimentation, 470, 551, 14-13 Set operations, 23 Shewhart control charts, 600, 632 Sign test, 572, 575, 578, 579, 593 Sign test for paired samples, 576 Sign test, table of critical values, 671

Significance level of statistical test, 281, 292 Significance of regression, 385, 387, 388, 428 Simple linear regression model, 374 Single replicate of factorial design, 537 Single-factor experiment, 469, 470 Six-sigma process, 623, 624 Six-sigma quality, 140 Sources of variability, 3 Sparsity of effects principle, 537 SPC. 11: also see Statistical process control Special cause of variation, 598 Stability, 4 Standard deviation of random variable, 66, 105 Standard error of point estimator, 225, 265 Standard error of regression coefficients, 384 Standard normal distribution, 113, 114, 240 Standard normal random variable, 111, 113, 114 Standardized control chart, 647 Standardized residuals, 396, 442 Standardizing normal random variable, 113, 114 Statistic, 197, 221 Statistical inference, 4, 221, 238, 327; also see Hypothesis testing, Parameter estimation Statistical process control, 11, 597; also see SPC Statistical quality control, 596, 597 Statistical thinking, 3 Statistical versus practical significance, 298, 299 Statistics (the field), 2 Stem-and-leaf diagram, 197, 198, 200, 204, 210 Stepwise regression, 457 Strong versus weak conclusions in hypothesis testing, 285 Studentized residual, 443 Subjective probability, 28 Subjective view of probabilities, 7-3

t-Distribution percentage points, table of, 656 t Distribution, 258, 8-2, 301 Tabular CUSUM procedure, 634, 636 Tampering with a process, 8 Taylor series, 12-8 Test for homogeneity in contingency table, 322 Test for independence in contingency table, 320 Test for lack of fit in regression, 11-1 Test statistic, 279, 289, 301, 307, 311, 316, 321, 322, 9-1 Testing for curvature, see Center points in 2^k factorial design Testing for trends, 593 Third (or upper) quartile, 200 Three-factor factorial experiment, 520 Three-factor interaction, 532 Three-sigma control limits, 603, 630 Ties in Kruskal-Wallis test, 589 Ties in sign test, 575 Ties in Wilcoxon signed-rank test, 583 Time series plot, 8, 209 Time series, 8, 209 Tolerance chart, 619 Tolerance interval, 247, 248, 270, 275 Tolerance intervals for normal distribution, 270 Total probability rule, 43, 44, 52 Total sum of squares, 380, 473 Transformations, 217, 400, 11-4 Treatment effect, 472 Treatment sum of squares, 474, 488, 493 Treatments, 472, 492, 493 Tree diagram, 21, 22, 45 Trend in data, 210

Trimmed mean, 219 Tukey's test, 13-4 Two-factor factorial experiment, 510, 514, 517 Two-factor interaction, 507 Two-factor interaction plots, 508 Two-factor mixed model, 14-6 Two-factor random effects model, 14-4, 14-5 Two-sample confidence intervals, 334, 335, 345, 346, 352, 359, 365 Two-sample hypothesis tests, 7, 327, 329, 337, 341, 349, 357, 361, 364, 10-3 Two-sided alternative hypothesis, 279, 286 Type I error, 280 Type II error for sign test, 578 Type II error, 282, 293, 312

U

U-chart, 627, 628 Unbalanced experiment, 479 Unbiased estimator, 222, 223, 224, 379, 383, 421 Uniform distribution: Discrete, 70 Continuous, 107 Union (set operation), 23 Uniqueness property of moment generating functions, 5-11 Unreplicated factorial design, 537 Upper confidence limit, 250 Upper control limit, 10, 599

V

Variability, 3, 191 Variable selection in regression models, 432, 452, 453, 457, 458, 459 Variables control charts, 601 Variance components, see components of variance Variance of linear combination of random variables, 181 Variance of point estimator, 223, 226 Variance of population, 193 Variance of random variable, 66, 105 Venn diagram, 24 Verifying assumptions, 213, 302; *also see* Model adequacy checking *V*-mask procedure for CUSUM, 633

W

Warning limits on control charts, 607
Weibull distribution, 134
Weibull probability plot, 6-2
Weibull random variable, 134
Weighted least squares, 409
Western Electric rules for control charts, 606
Wilcoxon rank-sum test, 585, 587, 588
Wilcoxon rank-sum test, table of critical values, 672
Wilcoxon signed-rank test, 579, 581, 583, 584
Wilcoxon signed-rank test, table of critical values, 671

X

 \overline{X} control chart, 607, 608

Z z-value, 114