Index

0-1 knapsack problem, 51
0-1 programming problems, 50, 52
αBB branch-and-bound method, 283
α-ECP (solver), 288
AARC (affine adjustable robust counterpart) problem, 342
Accuracy, dynamic adjustment of, 523
"Act, learn, then act" approach, 458
"Act, then learn" approach, 458
Active-set method
  for linearly constrained optimization, 503
  for nonlinear optimization, 224, 232–233
  QP solvers using, 232–233
Adaptability, in recourse-based robust optimization, 342–343
Adaptive radiation therapy, 350
Adaptive robust UC model with net load uncertainty, 360–362
Adjoint method, 252
Adjustable robust solutions, 340–342
Advection equation, 125
Adverse selection, 474
Aerodynamic shape optimization, 252–254
Aerospace engineering, 249–250
Aerospace systems
  computational models, 250
  described, 249–250
  gradient computation, 251–252
  multidisciplinary design optimization for, 249–257
  optimization algorithms, 251
  optimization problems, 250–251
  satellite design and operation, 256–257
Aerostructural design optimization, 254–256
Affine adjustable robust counterpart (AARC) problem, 342
Affine adjustable robust solutions, 342
Affine policy–based robust optimization model, 365
AGC (automatic generation control) units, 364–365
Aggregated models, for process synthesis, 317–318
AIMMS modeling system, 91, 223, 287–288
Aircraft conflict avoidance, 294–301
  history of approaches, 294–295
  MINLP formulations, 295–300
  solution approaches, 300–301
Aircraft deconfliction, 294
Air quality constraints, in building automation, 263
Air quality control systems, 260–261
Air separation systems
  distillation columns in, 244
  distillation models for, 246, 247
  production planning for, 78–82
Air traffic management (ATM), 293–301
  aircraft conflict avoidance, 294–295
  automation in, 293
  MINLP formulations, 295–300
  solution approaches, 300–301
Algebraic modeling languages, 287
ALGENCAN (solver), 235
Algorithmic differentiation, 252
Algorithm(s)
  global optimization, 168–172
  linear optimization, 5–6
  for MDO in aerospace systems, 251
  nonlinear optimization, 229–235
    augmented Lagrangian methods, 235
    generalized reduced gradient method, 235
    interior-point methods, 233–235
    sequential quadratic programming, 229–233
  POUNDERS, 533–535
  quadratic optimization, 7
All-atomistic validation, 176
Allocation centers, in inventory modeling, 485
Alternate heuristic (ALT), for pooling problems, 212–213
AMBER energy values, 180–181
Ambiguity set, 344
AMPL modeling system, 223, 268–269, 287, 288, 290

Ancillary services markets, 462, 463
Annual vaccine strain selection problem, 472
ANTIGONE (solver), 289
Approximation(s)
  for biofuel production decisions, 465
  gradient, 512–513
  for nonlinear optimal control, 129–133
  for optimal power flow problem, 197–198
  outer approximation technique, 170–171, 198–202, 277
  piecewise-linear, 283–284
  for pooling problem, 213–214
  power, 446
  quasi-Newton, 227, 497
  robust, 31–32
  sample average, 382, 390
  stochastic, 381–382, 390
  successive approximation techniques, 170–171
Arc-flow formulation, for LNG inventory routing, 83
Asset risk contribution, 432
ATM. *See* Air traffic management
ATM (company), 75
Attainable region, of reactor networks, 320
Augmented Lagrangian function, 229, 235, 504
Autocorrelation coefficients, 29
Automatic differentiation techniques, 223
Automatic generation control (AGC) units, 364–365
Automation
  in air traffic management, 293
  building, 259–269
    building operations and inefficiencies, 260–261
    computational considerations, 268–269
    physical building model, 261–262
    predictive control, 262–268
  HVAC system, 259
  plant, model predictive control in, 44–46
Automotive valve trains, 508
Average occupation measures, 131–133
Averaging, noise reduction via, 523

Backbone superpositions, 527
Backorders, 441, 445
Backward pass, for SDDP algorithm, 417, 418
Balinski–Tucker procedure, 9
BARON (solver), 217, 289, 313–314
Barrier methods. *See* Interior-point methods (IPMs)
Barrier parameters, 233
Barrier term, 233
Base-stock policy, 445, 446, 449
Basis pursuit, 32
Basis solution, interior vs., 9
BC-DFO (solver), 498
Benchmark tracking problem, 152
Benders cuts, 417
Benders decomposition, 71–72, 279, 283
BFGS formula, 227, 231
Big-*M* formulations, 69, 70
Bilevel leader-follower game model, 464
Bilevel optimization
  for biofuel production, 464, 466
  in energy industry, 454
  for pooling problem, 212
Biofuel production
  feedstock procurement for, 463–465
  supply network design for refineries, 465–466
Biological applications of optimization, 175–176
Biological constraints, in protein-DNA system design, 178, 183
Biorefinery locations, 465–466
Black-box MIP solvers, 57–58
Black-box optimization problems, 529
Blenders, in biofuel supply chain, 465
Blending equations, in scheduling models, 328
Blending problem, 207
Blocking, in no-wait job-shop scheduling, 69
Blood and blood products, inventory management for, 473, 484–487
BMSs (building management systems), 259
BOBYQA (solver), 503
Bombardier Transportation, 75
Bonmin (solver), 288
Boolean variables, 316
Bottlenecks, transportation network, 487–491
Bounds
  for branch-and-bound method, 169
  in global optimization, 169
  lower, 129, 274
  propagation of, 281
  for spherical codes, 34
  tightening of, 281–282
  upper, 274, 428, 431
  worst-case complexity, 448, 501–502
BPMPD (solver), 11
Brachytherapy, 99–101
Branch-and-bound method
  αBB, 283
  bounds for, 169
  branching in, 169
  for global optimization, 169–170
  for integer optimization, 51, 52
  and lift-and-project tool, 55, 56
  for Lipschitz optimization, 172
  LP/NLP-based, 278–279

for mixed-integer nonlinear optimization, 274, 283
nonlinear, 275–276
pruning in, 169
solving UFLPs with, 451
spatial, 204–205, 280–281, 284
termination of, 170
Branch-and-bound tree, 275
Branch-and-cut method, 56, 102, 278
Branch-and-reduce method, 281–282
Branch callback, 63
Branching, 169, 274, 280, 285
Brand-name drugs, 475–477
Breakdowns, corridor, 489
Breast milk bank, 480–483
Budgeted uncertainty set, 361
Budget of uncertainty, 361
Building automation, 259–269
building operations and inefficiencies, 260–261
computational considerations, 268–269
HVAC system automation, 259
physical building model, 261–262
predictive control, 262–268
Building management systems (BMSs), 259
Building operations, 260–261
Building-wide control strategy, 267–268
Building-wide models, 261
Building-wide nonlinear variable interactions, 259–260
Bundle methods, 118, 452
Buyback contracts, 454–455

CADANS (software), 59
CAES (compressed-air energy storage), 462
Callback functions, MIP solver, 62–63
Cantilever beam, minimum volume problem with, 22, 24
Capacity-based disruption, 478
Capacity certainty, for power generators, 459–461
Capacity expansion
in chemical engineering, 77
in energy industry, 187, 365, 466
in healthcare, 470
and inventory optimization, 439
Capacity planning
in energy industry, 457–458
in healthcare, 469–470
Capacity uncertainty, 448
Cap-and-trade mechanisms, 464–465
Cardinality-constrained uncertainty set, 336–337
Categorical variables, derivative-free optimization for, 506
Cauchy ordinary differential equation (ODE), 127–128
CCHP plants. *See* Combined cooling, heat, and power plants
CCSO. *See* Chance constrained stochastic optimization
Centralization, of distribution locations, 486–487
Central path, 116
Centroid-centroid force fields, 178–179, 182, 183
CEOS (cubic equation of state), 242, 246
Certificate of infeasibility, 277
CGLP (cut-generating linear program), 56, 287
Chance constrained stochastic optimization (CCSO), 387–389, 391
in chemical engineering, 393, 394
distributionally robust models, 390, 391
in financial engineering, 428, 429
Change parameter command, 61
Chemical engineering
linear and quadratic optimization, 37–46
design and operations applications, 37
model predictive control, 41–46
production planning, 37–41
mixed-integer linear optimization, 77–91
chemical supply network optimization, 86–90
LNG inventory routing, 82–86
production planning for air separation plants, 78–82
mixed-integer nonlinear programming, 291–292
stochastic optimization, 393–404
CVaR-based method, 401–404
operational planning in chemical plants, 393–394
problem statement, 394–397
robust optimization method, 397–400, 403–404
Chemical plants
operational planning in, 393–394
pooling problem in, 207–208
Chemical supply network optimization, 86–90
Child nodes, 275
CHP (combined heat and power) plants, 303
Chvátal rank, 54
Circuit placement, 33–34
Classification problems, 94, 96–99
CLO. *See* Conic linear optimization
Closed-form solutions
for EOQ problem, 441
for infinite-horizon problems, 446
for multiechelon inventory optimization, 449
for single-reservoir model, 412
CLP (solver), 11
COBYLA (solver), 505
Coefficient reduction, 285
Cogeneration energy systems, 303–314
computational experiments for, 310–314

data-driven vs. first-principles approaches to, 304–305
described, 303–304
MINLP formulations for, 307–310
unit commitment vs., 305–307
variations in, 305
Cogeneration power plants, 303
Coherent risk measures, 390
Collaborative R&D, 474–475
Column-and-constraint generation algorithm, 362
Combinatorial optimization, 52–53, 165
Combined cooling, heat, and power (CCHP) plants
computational experiments, 310–314
MINLP formulation for, 307–310
unit commitment in, 306–307
Combined heat and power (CHP) plants, 303
Comfort overrelaxation strategy, 266–269
Committed service time (CST), 449–450
Communication networks, 36
Competitive feedstock procurement, 463–465
Complementarity conditions
for linear optimization, 4
for nonlinear optimization, 225
for second-order cone optimization, 116
Complementarity constraints
MPCCs, 235
column optimization with phase changes, 242–243
distillation column optimal design, 243–245
distillation systems, 240–241
in semidefinite optimization, 116
Complementarity pivot algorithms, 7
Complementarity problems, 167, 535
Complementary optimal solutions, 4
Completely positive cones, 112–113
Complete polling, 499
Complete quadratic models, 497
Complete water networks (CWNs), 326
Complexity
for dynamic economic lot-sizing problem, 442
of global optimization, 166–167
of LO and QO, 8–9
and MINLO software, 288–291
of nonlinear optimization problems, 224
worst-case complexity bounds, 448, 501–502
Complex-step method, 252
Compliance function, 138
Component mass balances, distillation column, 239
Composite step-based SQP, 505
Compressed-air energy storage (CAES), 462
Compressed sensing, 32, 497
Computational complexity. *See* Complexity
Computational methods, LO and QO, 9–10
Computational models for aerospace systems, 250
Computed tomography (CT) images, 346
Computer systems
optimization algorithms, xxix
power of, xxix–xxx
Concave minimization (concave optimization) problems, 164, 170–171
Concentration model. *See* P-formulation
Conditional distribution, stochastic optimization with, 384
Conditional probability, from scenario trees, 385
Conditional value-at-risk (CVaR), 394
in chemical engineering, 401–404
and distributional robustness, 350
for investment portfolio construction, 430–432
marginal CVaR contribution for assets, 434
maximization return problem with upper bound on, 431
mean-CVaR model, 431
minimization of CVaR problems, 431
and z transformations, 401
Conflict-free trajectory planning, 295
Conflict resolution, for aircraft, 294
Conflicts
between aircraft, 294
between objectives, 479, 480
in train dispatching, 68
Congestion delays, 490–491
ConicBundle (software), 118
Conic constraints, 235, 338
Conic linear optimization (CLO), 107–120
with convex uncertainty set, 337–338
duality and constraint qualification, 113–115
financial engineering, 149–160
equal-risk contribution portfolios, 157–160
linear optimization models, 149–150
portfolio optimization problems, 151–153
robust mean-variance optimization, 155–157
SOCO problems, 150–151
transaction costs with market impact, 153–155
general conic optimization, 111–113
nonlinear optimal control, 121–133
approximation results, 129–130
control over set of initial conditions, 130–133
history of optimal control, 121–122
LP formulation, 125–129
polynomial optimal control, 122–124
optimality conditions and interior-point algorithms, 115–116
polynomial optimization, 119–120
second-order cone optimization, 110–111
semidefinite optimization, 107–110

software, 117–119
truss topology design, 135–147
applications, 144
integer variables, problems with, 145–147
nonlinear optimization formulation, 136–139
SDO formulation, 141–143
SOCO formulation, 139–141
truss notation, 135–136
vibration constraints, 144–145
CONOPT (solver), 196, 235, 242, 244
Conservation of mass, equation of, 127
Conservativeness, of SCUC model, 363–364
Constraint disaggregation, MINLP problems with, 285
Constraint qualification (CQ)
linear-independence, 225, 226
Mangasarian–Fromowitz, 225
Slater's, 114–115
Constraints. *See also* Complementarity constraints
for aircraft conflict avoidance, 296, 299
basic distillation model, 240
building automation, 263–264
column-and-constraint generation algorithm, 362
complementarity, 116
conic, 235, 338
derivative-free optimization, 495, 504–505
dose-volume, 94
equilibrium, 465
hidden constraint problems, 507–517
convergence results, 510–514
`imfil.m` code, 514–517
implicit filtering, 508–510
with random directions, 515–517
investment portfolio construction with, 432–435
knapsack, 430
LB, 58
linear, 335–338, 511
marginal VaR and CVaR, 432–435
nonanticipativity, 386
nonlinear
general uncertainty set, 338–339
MINLP model for cogeneration systems, 309–310
robust optimization with uncertainty, 338–339
optimal power flow problem, 189
periodic event-scheduling problem, 59
polyhedral, 266, 269
pooling problem, 210
portfolio optimization, 151–153
positive semidefiniteness, 56
protein-DNA system design, 178–180, 182, 183
reformulation-linearization technique, 180
relaxable, 504–505
spectral mask, 29
TE, 152–153
thermal comfort, 263–264
in train-dispatching problem, 68–69
unrelaxable, 504, 505, 535
vibration, 144–145
Constraint softening, 44
Construction heuristics, 84
Consumers, strategic behavior by, 471–472
Continuity equation, 125
Continuous-demand problems, 446–448
Continuous location models, 450–451
Continuous operating decisions, 78–79
Continuous relaxation, in branch-and-bound method, 274
Continuous-review models, 440, 447–448
Continuous variables
in GDP models, 316
in global optimization, 164–165
Contracts
buyback, 454–455
cost-sharing, 471
decentralized supply chain optimization for, 453–455
fail-to-supply, 477–478
fee-for-service, 475–477
in healthcare, 473–478
licensing, 474–475
wholesale price, 454
Control(s). *See also* Model predictive control (MPC); Optimal control
building automation, 260, 261, 265–266
dynamic matrix, 41, 42
hybrid process, 317
inventory control policy, 462, 473
LO and QO for, 27
over set of initial conditions, 130–133
process, 37, 317, 328–329
relaxed, 125–126
subliminal, 294
tumor control probability, 99–101
Convergence
global convergence
defined, 496
derivative-free optimization with, 501–502
nonlinear optimization with, 227–228
for hidden constraint problems, 510–514
geometry of D and necessary conditions, 510
gradient approximation, 512–513
limitations, 514
Lipschitz-continuous f, 513–514
search direction sets, 511–512

for implicit filtering, 509–510
for nonsmooth functions, 500
and sampling using simplex sets, 498
and SDDP algorithm, 417–418
uniform, 130, 132–133
Conversion loss, 462
Convex analysis, cutting-plane approach with, 54–55
Convex cost network flow model, 487, 490–491
Convex envelope, 167
Convex hull search technique, 213–214
Convexity
identifying, 166–167
in nonlinear optimization, 163
Convex MINLP, 274–279
defined, 274
LP/NLP-based branch-and-bound approach for, 278–279
nonlinear branch-and-bound approach for, 275–276
outer approximation algorithm for, 277
polyhedral relaxations for, 276–277
solver software for, 288–289
Convex nonlinear optimization problems, 222–223
Convex objective function
deterministic inventory optimization with, 441
multiechelon inventory optimization with, 449
stochastic inventory optimization with, 444
Convex optimization problems, 107, 382. *See also* Conic linear optimization
Convex outer approximation (OA)
for optimal power flow problem, 198–202
via McCormick envelopes, 196–197
via piecewise-linear envelopes, 199–202
Convex quadratic constraints, 151–153
Convex uncertainty set, 337–338
Coordinated supply chains, 453–455
Coordinate search, 509–511
Coordination collar, 45–46
Copositive cone, 112–113
Corners, in breast milk bank system, 481
Corrective actions, SCUC model with, 363
Corridor breakdowns, 489
Corridor delays, 487–489
Cosine measure of PSSs, 499
Cost functions, 40, 296
Cost-sharing contracts, 471
Cost-to-go functions
stochastic optimization with, 384–385
supply chain optimization with, 442, 445, 450
COUENNE (solver), 289, 313–314
Coupled modeling approach, 467
Coupled systems, 250, 261
Covering models, 453
CPLEX (solver), 10, 22–25, 56, 82, 85–86, 202, 217, 399, 402, 450
CQ. *See* Constraint qualification
CreditMetrics, 432
Crew scheduling problem, 59
Criss-cross type algorithms, 5
Critical fractile (critical ratio), 444
CSPD (solver), 117
CST (committed service time), 449–450
CT (computed tomography) images, 346
Cubic equation of state (CEOS), 242, 246
Cut-generating linear program (CGLP), 56, 287
Cuts
Benders, 417
flow cover, 450
rounds of, 56
Cutting-plane method
extended, 279
for integer optimization problems, 53–54
and lift-and-project tool, 55–56
for MINLP problems, 286–287
and SDDP algorithm, 417
CVaR. *See* Conditional value-at-risk
CVX (environment), 117, 119
CWNs (complete water networks), 326
Cycling cost, 460

$\mathscr{D}$, geometry of, 510
Daily production profile, chemical plant, 393
DAMIP (discriminant analysis via MIP), 96–99
Data-driven black box approaches, 304–305
Data set construction, protein-binding cavity, 525–526
Day-ahead electricity markets, 405
D.C. (difference of convex) functions, 166, 168
DC (direct current) power flow linearization, 197–198
DDF (differentiable distribution function), 243–244
DDNA3 energy, 181
Decentralized supply chains, 453–455
Decision-hazard problems, 413
Decision-making problems, in power system operations, 357–358
Decision support tools, 482–483, 492
Decision Tree for Optimization Software Website, 222
Decision variables
for aircraft conflict avoidance, 295–296
in optimal power flow problem, 189
for short-term cogeneration systems planning, 307–309
Decoding techniques, 35

Decomposition
  Benders, 71–72, 279, 283
  nested, 386, 389–391
  for nonconvex MINLP problems, 283
  in process flowsheet synthesis, 318
  scenario, 386, 389, 391
  stochastic, 391
  for train dispatching applications, 70–72, 74
Defender-attacker-defender model, 341–342
Degenerate LO problems, 5–6
Degrees of freedom, 224, 531
DEL (dynamic economic lot-sizing problem), 442–443
Delay modeling
  in delivery routing, 489–491
  for port and corridor delays, 487–489
Delivery routing, 489–491
DELTA Supply Chain, 60–61
Demand distribution, 444–448
Demand uncertainty
  in chemical engineering, 393–394
  in robust optimization method, 397
Derivative-based methods, 251
Derivative-free optimization (DFO), 495–506
  aerospace applications, 251
  described, 529–530
  extensions, 506
  global, 169
  linearly constrained optimization, 502–503
  nonlinearly constrained optimization, 503–506
    extensions, 506
    model-based trust-region methods, 505–506
    relaxable constraints, 504–505
    unrelaxable constraints, 504, 505
  POUNDERS solver, 529–539
    algorithm underlying POUNDERS, 533–535
    and DFO described, 529–530
    energy density functional calibration, 536–539
    smooth residual models, 530–533
    Toolkit for Advanced Optimization software, 535–536
  protein-binding cavity alignment via DFO-VASP, 519–528
    computational experiments, 525–527
    DFO method, 521–522
    electrostatic data, 521
    noise-handling strategies for VASP, 522–525
    protein specificities, 519–520
    VASP method, 520
  unconstrained optimization, 496–502
    noisy functions, 500–501
    nonsmooth functions, 499–500
    probabilistic models, 502
    smooth functions, 496–499
    worst-case complexity and global convergence, 501–502
  uses, 495
Derivatives, availability of, 223
Descent direction, 225
Design template, protein-DNA system, 177–178, 182
Deterministic approaches
  for aircraft conflict avoidance, 300
  for electric power systems, 358
  for inventory optimization, 440–443
  for security-constrained unit commitment, 359–360
Deterministic convex problems, 388
DFO. *See* Derivative-free optimization
DFO (solver), 498, 503, 505
DFO-VASP protein-binding cavity alignment, 519–528
  computational experiments, 525–527
  DFO method, 521–522
  electrostatic data, 521
  noise-handling strategies for VASP, 522–525
  protein specificities, 519–520
  VASP method, 520
Diagnosis, integer optimization in, 93–94
Dicopt (solver), 289
Difference gradient, 512
Difference of convex (D.C.) functions, 166, 168
Differentiable distribution function (DDF), 243–244
DIRECT (solver), 172, 506, 508
Direct current (DC) power flow linearization, 197–198
Directions, sampling along, 502–503
Direct methods for evaluating derivatives, 252
Direct noise level reduction, 523
Direct-search methods
  linearly constrained optimization, 502–503
  nonlinearly constrained optimization, 504
  probabilistic descent, 502
  unconstrained optimization, 498–499
  worst-case complexity bounds, 501–502
Disaster mitigation, 480
Disaster preparedness, 480, 483–484
Disaster recovery, 491
Disaster response, 483–484
Discontinuities, aerospace system, 251
Discounting
  and finite-horizon problem, 445
  for marginal water values, 412–414
Discrete-continuous optimization, 316
Discrete facility location model, 465–466
Discrete location models, 451

Discrete operating decisions, 78–79
Discrete optimization, 164. *See also* Integer optimization
Discrete stochastic optimization problems, 389
Discretization
  in building automation, 268–269
  in conic linear optimization, 121, 129
  in mixed-integer linear programming, 213–214, 217
  of radiation doses, 347–348
  in supply chain optimization, 445
  of three-dimensional PDEs, 224, 231
Discriminant, in aircraft conflict avoidance, 297
Discriminant analysis via MIP (DAMIP), 96–99
Disease detection, 93–94
Disjunctions, GDP model, 316
Disjunctive precedence constraint, 68–69
Disjunctive programming, 69, 286–287. *See also* Generalized disjunctive programming (GDP)
Dispatching, train. *See* Train dispatching
Displacement-like variables, in truss topology design, 19
Disruptions, supply, 448, 477, 478
Distillation column
  basic model of, 238–240
  MPCC formulation of, 240–241
  optimal design of, 243–245
  with phase changes, 242–243
Distillation sequences, 323–324
Distillation systems, 237–247
  basic distillation model, 238–240
  case studies of, 241–245
  described, 237–238
  extensions of nonlinear optimization for, 245–247
  MPCC formulation for, 240–241
Distributed parameters, 62
Distributionally robust optimization (DRO), 344
Distributional robustness
  chance constrained SO models with, 390, 391
  linear optimization for, 348–350
  in radiation therapy, 348–350
  stochastic optimization models with, 390, 391
Distributional uncertainties, in wind farm layout, 368
Distribution locations, in inventory modeling, 485–487
DMC (dynamic matrix control), 41, 42
DNA. *See* Protein-DNA system design
DOASA software, 419
Dose-volume constraints, 94
Dow Chemical Company, 78, 86–90
DP (dynamic programming) formulation, 442, 450
Drag coefficient, 253
DRO (distributionally robust optimization), 344
Drugs. *See* Pharmaceuticals
Drug shortages, mitigating, 477–478
DSDP (solver), 118
Dual capacity sourcing problem, 469–470
Dual cone, 112
Duality, xxx, 113–114. *See also* Strong duality condition
DUALOC algorithm, 452
Dual problem
  in nonlinear optimization formulation, 139
  for optimal control applications, 129
  in second-order cone optimization, 140–141
  in semidefinite optimization, 108, 142–143
  in truss topology design, 139–142
Dual-response manufacturing, 458
Dual simplex method pivot rules, 5–6
Dynamic adjustment of accuracy, 523
Dynamic distillation systems, 246–247
Dynamic economic lot-sizing (DEL) problem, 442–443
Dynamic matrix control (DMC), 41, 42
Dynamic programming (DP) formulation, 442, 450
Dynamic stochastic optimization, 382–387
  electricity prices from, 406
  in energy industry, 461
  formulations for, 384–387
  supply chain engineering application, 382–384

ε-subdifferential, 168
Echelon base-stock level, 449
Echelon base-stock policy, 449
Echelon holding costs, 449
Echelons, inventory, 449
Economic curtailment policy, 461
Economic dispatch (ED) problem
  electricity prices from, 406
  and optimal power flow problem, 187
  and power system operations, 459
  robust optimization model for, 364
  security-constrained, 191
Economic lot-sizing problem (ELSP), 442–443
Economic order quantity (EOQ) problem, 440–442
Economic production quantity (EPQ) problem, 442
ECP (extended cutting plane) method, 279
EDFs (energy density functionals), 536–539
ED problem. *See* Economic dispatch problem
Efficiency–responsiveness trade-off, in strategic sourcing, 457–458
Efficient frontier, 149

Elastic equilibrium equations, 15, 16
Electrical engineering
  communication networks, 36
  filter design, 28–30
  information and coding theory, 34–35
  linear and quadratic optimization, 27–36
  norm optimization, 31–34
  pattern classification, 30–31
Electric power systems
  marginal water valuation in, 419–425
  reliability of, 357
  robust optimization, 357–365
    decision-making problems in power system operations, 357–358
    extensions, 362–364
    real-time operation and long-term planning, 364–365
    security-constrained unit commitment model, 359–362
Electrostatic isopotentials, 521
Ellipsoidal uncertainty set, 335–336, 338, 339
ELSP (economic lot-sizing problem), 442–443
Embedded optimization, 27
Emergency facility location problem, 51
Energy arbitrage, 463
Energy balances, in physical building model, 262
Energy consumption, by distillation systems, 237
Energy density functionals (EDFs), 536–539
Energy industry
  feedstock procurement, 463–465
  inventory management, 461–463
  power system management, 457–461
  supply chain optimization, 457–467
  supply network design, 465–467
Energy metric, protein-DNA system design, 176, 181–182
Energy optimization, xxx. *See also* Short-term planning in cogeneration energy systems
Energy output, wind farm layout and, 367
Energy storage facilities, 461–463
Enhancement techniques
  MINLO, 284–287
    cutting planes, 286–287
    presolve, branching, and reformulations, 284–285
    primal heuristics, 285–286
  stability enhancement, 44, 372–374
Enolase superfamily, 525, 526
Enthalpy, 239
Enumerative approach, 52, 170. *See also* Branch-and-bound method
Envelope-based relaxations, 214–215
Environmental Protection Agency (EPA), 208, 458
EOQ (economic order quantity) problem, 440–442
EOQ with backorders problem, 441
EPA (Environmental Protection Agency), 208, 458
EPQ (economic production quantity) problem, 442
Equality-constrained NLO problems, 230–231
Equal-risk contribution (ERC) portfolios, 157–160
Equilibrium constraints, 465
Equilibrium demand, 472
Equilibrium relations, distillation column, 239
Equity objectives, in humanitarian applications, 480–483
ERASMUS, 294, 295
ERC (equal-risk contribution) portfolios, 157–160
Euler's theorem, 433
Exact, maximally complementary primal-dual optimal solution pair, 9
Exact, strictly complementary primal-dual optimal solution pair, 9
Exact penalty function, 228–229
Expectation objective, 381
Extended cutting plane (ECP) method, 279
Extreme barriers, 504
ExxonMobil, 78

Facial programs, 55
Facility location problem
  in energy industry, 463, 465–466
  in healthcare logistics, 95
  in humanitarian applications, 480–483
  integer optimization for, 50–51, 95
  in supply chain optimization, 450–453
Factorable programming, 279–280
Fail-to-supply (FTS) contracts, 477–478
Fairness, in humanitarian supply chain optimization, 480, 483, 491
Fathoming, 169, 275
FBBT (feasibility-based bound tightening), 281
FCFS (first-come, first-served) usage, 485–487
FDA (Food and Drug Administration) approval, 469, 474
Feasibility-based bound tightening (FBBT), 281
Feasibility pump (FP), 57, 286
Feasible IPMs, 6
Feasible methods for nonlinearly constrained optimization, 504
Feasible set, for branch-and-bound method, 274
Feasible solution, from polyhedral relaxations, 277
Feedstock procurement, 463–465
Feed tray location, distillation column, 320–323
Fee-for-service (FFS) contracts, 475–477
FFS (fee-for-service) contracts, 475–477

FILMINT (solver), 289
Filter design, LO and QO for, 28–30
Filter methods, 229, 505
FILTERSQP (solver), 233
Financial engineering
  conic linear optimization models, 149–160
    equal-risk contribution portfolios, 157–160
    linear optimization models, 149–150
    portfolio optimization problems, 151–153
    robust mean-variance optimization, 155–157
    SOCO problems, 150–151
    transaction costs with market impact, 153–155
  optimization applications, xxx
Financial optimization, 149, 427
Finite-horizon inventory problem, 445–446
Finite-horizon stochastic dynamic programming model, 470
Finite impulse response (FIR) filters, 28
FIR (finite impulse response) filters, 28
First-come, first-served (FCFS) usage, 485–487
First-order conditions
  for distillation models, 246
  in inventory optimization, 441, 444, 448, 454, 455
First-order methods
  for global optimization, 169
  for unconstrained optimization of smooth functions, 496–497
First-principles approaches, 304–305
Fixed block signaling systems, 66
Fixed charge problem, 50, 164
Fixed cost(s)
  in chemical engineering, 87, 90
  in dynamic economic lot-sizing problem, 442
  in energy systems, 308, 359
  in EOQ problem, 440–442
  in facility location problem, 451, 453
  in finite-horizon problem, 445
  in infinite-horizon problem, 447
  in multiechelon inventory optimization, 449
Flexible capacity, in healthcare, 470
Flexible mode, QP solver, 233
Flight level, changes in, 294
Flow cover cuts, 450
Flow model. *See* P-formulation
Fold specificity, protein-DNA system, 180–181
Food and Drug Administration (FDA) approval, 469, 474
Food-energy-environment trilemma, 464
Forward pass, for SDDP algorithm, 417, 418
FP (feasibility pump), 57, 286
Fractional linear optimization problem, 167
Franz Edelman Award, 58
Freight trains, dispatching of, 74
FTS (fail-to-supply) contracts, 477–478
Fuel burn, 254–256
Fukushima tragedy, 458
Full-Newton model, 533
Fully adjustable robust solutions, 340–341
Fully flexible power generators, 460
Fully linear models, 496–497
Fully quadratic models, 497

Game theory, contract analysis in, 453–455, 474
GAMS (software), 195–196, 205, 223, 244, 399, 402
Gasoline blending, 208
Gauss–Newton model, 533
GBD (generalized Benders decomposition), 279, 283
GDP. *See* Generalized disjunctive programming
Gegenbauer polynomials, 34
General conic optimization problem, 111–113
Generalized Benders decomposition (GBD), 279, 283
Generalized disjunctive programming (GDP), 315–329
  general model, 316
  linear, 317
  molecular computing, 329
  planning and scheduling, 327–328
  process control, 328–329
  process synthesis, 317–327
  superstructure, 315–316
  types of models, 316–317
Generalized pattern search, 499
Generalized pooling problem, 211
Generalized reduced gradient method, 235
General purpose solvers, 233–235
General uncertainty set, 338–339
Generation contingencies, SCUC model with, 364
Generic drugs, fail-to-supply contracts for, 477–478
Gibbs–Duhem relation, 241
Gibbs free energy, 240
Gini coefficient, 480
Global convergence
  defined, 496
  derivative-free optimization with, 501–502
  nonlinear optimization with, 227–228
Globally optimal solutions, 222–223
Global minima
  in aerospace applications, 251
  and CLO problems with integer variables, 145
  for concave minimization problems, 164, 170, 172
  for convex vs. nonconvex problems, 163
  and termination of branch-and-bound algorithms, 170

Global optimality conditions, 167–168
Global optimization, 163–173
  algorithms, 168–172
  computational complexity, 166–167
  derivative-free optimization for, 506
  described, 163
  in medical treatment design, 95
  MIP in, 60
  optimality conditions, 167–168
  optimal power flow, 187–205
    convex outer approximation, 198–202
    example data and formulation, 192–197
    formulation, 189–190
    future research directions, 205
    Lagrangian relaxation, 202–203
    linear approximation with direct current flow, 197–198
    McCormick envelopes, 198–199
    moment sum of squares, 204
    OPF problem described, 187–188
    piecewise-linear envelopes, 199–202
    problem statement, 188
    solution methods, 191–205
    spatial branch-and-bound algorithm, 204–205
    sufficient strong duality condition, 203–204
    variants and extensions, 190–191
  pooling problem, 214–217
  protein-DNA system design, 175–185
    biological applications of optimization, 175–176
    energy metric, 181–182
    fold specificity, 180–181
    input parameters and constraints, 177–179
    methods, 176–177
    PFV integrase enzyme, 182–184
    protein-DNA sequence selection, 179–180
  software, 173
  types of problems, 164–166
GLOMIQO (solver), 196, 203
GloptiPoly, 120
GLPK (solver), 11
Goldfeld, Quandt, and Trotter (GQT) routine, 536
Governing equations, 250
Government intervention, supply chain optimization and, 464–465, 472
GQT (Goldfeld, Quandt, and Trotter) routine, 536
Gradient approximation, 512–513
Gradient-based methods, 169, 235, 501
Gradients
  for aerospace systems, 251–252
  difference, 512
  simplex, 500, 512
Grey-box optimization problems, 529
Ground structure approach, 13–14
Guaranteed-service model, 449
Gurobi (solver), 10, 56, 146

Hakimi property, 451
Half-wheel minimum volume problem, 22, 24
Hamilton–Jacobi–Bellman equation, 122
Hazard-decision assumption, 413
HDA (hydrodealkylation), 318–320
HDR (high-dose rate) brachytherapy, 99–101
Heading, changes in aircraft, 294
Healthcare
  humanitarian issues in global, 479, 491
  integer optimization applications, 93–103
    diagnosis and detection, 93–94
    discriminant analysis, 96–99
    health logistics and operations, 95
    open challenges, 102
    public health, 95
    solution strategies, 102
    TCP-driven PET-image-guided treatment-planning model, 99–101
    treatment design, 94–95
  optimization applications, xxx
  recourse-based robust optimization in, 344
  supply chain optimization, 469–478
    capacity planning, 469–470
    inventory management, 473
    production planning, 470–472
    supply chain contracting, 473–478
Healthcare facilities, inventory management at, 473
Health logistics, 95
Heat balances, distillation column, 239
Heat exchange networks (HENs)
  MINLO and GDP process synthesis applications, 324, 325
  models for, 317
Heat exchangers, in distillation systems, 238, 246
Heating, ventilation, and air-conditioning (HVAC) system, 259–261
HENs. *See* Heat exchange networks
Here-and-now decisions
  in marginal water value calculations, 413, 414
  robust optimization with, 340
  stochastic optimization with, 381
Heuristic callback, 63
Heuristic mode, MIP solvers, 61–62

Heuristics
  for integer optimization, 57–58
  for LNG inventory routing, 84–85
  for MINLP model of aircraft conflict avoidance, 300–301
  for MINLP problems, 285–286
  for pooling problem, 212–214
  in train-dispatching problem, 70
Hewlett Packard, 458
Hidden action, in licensing contract optimization, 474
Hidden constraint problems, 507–517
  convergence results, 510–514
  `imfil.m` code, 514–517
  implicit filtering, 508–510
  with random directions, 515–517
Hidden constraints, 507
Hidden information, 474
Hierarchical approach to planning and scheduling under uncertainty, 394
High-dose rate (HDR) brachytherapy, 99–101
Hölder condition, 172
Holding costs, 449
  in dynamic economic lot-sizing problem, 442
  in dynamic stochastic optimization, 382–383
  in EOQ problem, 440–441
  in finite-horizon problem, 445
  in infinite-horizon problem, 448
  local vs. echelon, 449
  in newsvendor problem, 443
Horn Rev wind farm, 368
Hospital readmissions, 96–99
Huber penalty function, 31
Humanitarian applications of supply chain optimization, 479–491
  bottlenecks in transportation networks, 487–491
  challenges, 479–480
  facility location, 480–483
  future perspectives, 491
  inventory modeling, 483–487
HVAC (heating, ventilation, and air-conditioning) system, 259–261
Hybrid process control, 317
Hydrodealkylation (HDA), 318–320
Hydroelectric generators, marginal water valuation for, 405–406
Hypergraphs, 102

IB (investment buying) model, 475–477
IDEAS (Infinite DimEnsion A1 State-space), 320
IFFCO (solver), 500
IIR (infinite impulse response) filters, 29
Image deblurring, 32
`imfil.m` code, 507, 514–517
Implicit filtering
  applications of, 508
  convergence theorem for, 509–510
  `imfil.m` code for, 514–517
Implicit function theorem, 252
IMPT. *See* Intensity-modulated proton therapy
IMRT. *See* Intensity-modulated radiation therapy
Incremental risk contributions, 432
Independent system operator (ISO), 358
Index tracking problem, 152
Indistinguishable scenarios, 385
Inequalities, information theory, 34–35
Infeasibility, certificate of, 277
Infeasible IPMs, 6, 8
Infimum, 124, 125
Infinite DimEnsion A1 State-space (IDEAS), 320
Infinite-horizon inventory problem, 446–448
Infinite impulse response (IIR) filters, 29
Inflow spreading, 420–421
Influenza vaccine, production planning for, 470–472
Information and coding theory, 34–35
Information-theoretic inequality prover (ITTP), 35
Informative callback, 62
INFORMS (organization), 58
Infrafraction motion, 348
Infrastructure deterioration, 465–467
Initial conditions, control over set of, 130–133
Inner approximation approach, 171
Integer optimization, 49–63
  for CCSO problems, 388–389
  combinatorial optimization, 52–53
  heuristics, 57–58
  impact of MIP technology, 58–61
  lift-and-project tool, 55–56
  medical and healthcare applications, 93–103
    diagnosis and detection, 93–94
    discriminant analysis, 96–99
    health logistics and operations, 95
    open challenges, 102
    public health, 95
    solution strategies, 102
    TCP-driven PET-image-guided treatment-planning model, 99–101
    treatment design, 94–95
  protein-DNA system design, 176–180
    input parameters and constraints, 177–179
    protein-DNA sequence selection, 179–180
  scope and applicability, 50–51
  solution methods, 53–55
  train dispatching applications, 65–75
    basic MILP models, 68–70

decomposition principle, 70–72
dispatching in railway systems, 65–68
real-life implementation, 72–75
using MIP codes, 61–63
Integer rounding, 53–54
Integer variables
derivative-free optimization for problems with, 506
truss topology design problems with, 145–147
Integrated facility location model, 466
Intensity-modulated proton therapy (IMPT), 345, 346, 354–356
Intensity-modulated radiation therapy (IMRT)
integer optimization in, 94–95
robust optimization in, 345–347, 355
treatment planning for, 346–347
Interfraction motion, 350
Interior-point condition (IPC), 6
Interior-point methods (IPMs)
active-set SQP methods vs., 224
complexity of, 8–9
for conic linear optimization, 116–118
extensions of, 11
implementation of, 9–10
interior optimal solution from, 9
for linear optimization, 6–11
for nonlinear optimization, 233–235
for quadratic optimization, 7
Interior solution, basis vs., 9
Interlocking routes, 66
Intermediate-capacity power generators, 460
Intermittent power generation, 459–461
Inventory control policy, 462, 473
Inventory level
in EOQ problem, 440–441
in finite-horizon problem, 445
in infinite-horizon problem, 446–448
in MILO for chemical engineering, 80, 84
Inventory management
in energy industry, 461–463
in healthcare, 473
Inventory modeling, for humanitarian applications, 483–487
Inventory optimization, 439–450
deterministic inventory optimization, 440–443
dynamic economic lot-sizing problem, 442–443
EOQ problem, 440–442
multiechelon inventory optimization, 449–450
stochastic inventory optimization, 443–448
finite-horizon problem, 445–446
infinite-horizon problem, 446–448
newsvendor problem, 443–444
supply uncertainty, 448
Inventory policies, 445–447
Inventory routing, liquid natural gas, 82–86
Investment buying (IB) model, 475–477
Investment portfolio construction, 427–435
CVaR models, 430–432
financial optimization, 427
with marginal VaR and CVaR constraints, 432–435
VaR models, 428–430
Iowa, energy industries in, 466
IPC (interior-point condition), 6
IPFILTER (solver), 234
IPMs. *See* Interior-point methods
IPOPT (solver), 11, 196, 234, 247, 268–269
ISO (independent system operator), 358
Isocenter optimization, 94
Italy
regional train dispatching in, 72–73
train dispatching at large stations in, 74
train dispatching for mass transit in, 75
ITTP (information-theoretic inequality prover), 35

Jensen model, 368–369
Job-shop scheduling problems, 69
Joint replenishment problem (JRP), 442

Karush–Kuhn–Tucker (KKT) conditions
in equality-constrained NLO problems, 230
in global optimization, 163, 167
in interior-point methods, 234
in MPCC formulation, 241
nonlinear optimization methods that satisfy, 163, 225, 226
in optimal power flow problem, 190, 192
K^*_{DNA} energy metric, 181–182
Kernel trick, 31
k-hypergraphs, 102
KKT conditions. *See* Karush–Kuhn–Tucker conditions
Knapsack constraint, 430
Knapsack problem, 51
KNITRO (solver), 233, 234–235, 289
Kreisselmeier–Steinhauser (KS) function, 255

LaGO (solver), 289, 290
Lagrangian function, 225
Lagrangian multipliers, 139, 225, 452
Lagrangian relaxation
in optimal power flow problem, 202–203
for pooling problem, 215, 216
solving UFLPs with, 452–453
in supply network design for energy industry, 466
LANCELOT (solver), 235

Large neighborhood search, 58
Large-scale cogeneration system, short-term planning in, 311–312
Lasso method, 33
Latin-hypercube sampling (LHS) technique, 525
Latvia, freight train dispatching in, 74
Lazy cut callback, 62–63
LB (local branching) constraint, 58
LB heuristic, 58, 286
LCP (linear complementary programming), 317
Leader-follower game model for biofuel production decisions, 464
Lead time
  and committed service time, 449–450
  in dynamic economic lot-sizing problem, 442, 443
  in energy industry, 457–459
  in EOQ problem, 440, 441
  in infinite-horizon problem, 447
  in pharmaceutical capacity planning, 469, 470
Lead-time demand, 447
Lead-time uncertainty, 448
"Learn, then act" approach, 458
Least-squares regression techniques, 500–501
Leibniz's rule, 444
LGDP (linear generalized disjunctive programming), 317
LHS (Latin-hypercube sampling) technique, 525
Licensing contracts, for new drugs, 474–475
LICQ (linear-independence constraint qualification), 225, 226
Lift-and-project tool, 55–56
Limited-memory quasi-Newton methods, 227
Limiting growth of a state, modeling, 124
LINDOGlobal (solver), 290
Linear approximation, for OPF problem, 197–198
Linear blending indices, 39
Linear complementarity problem, 167
Linear complementary programming (LCP), 317
Linear constraints
  direction sets for hidden vs., 511
  robust optimization with uncertainty in, 335–338
Linear generalized disjunctive programming (LGDP), 317
Linear-independence constraint qualification (LICQ), 225, 226
Linearizations, for mixed-integer nonlinear programming, 276
Linearly constrained optimization, 502–503
Linear matrix inequalities (LMIs), 110
Linear model predictive control, 317
Linear optimization (LO), 5–11. *See also* integer optimization
  algorithmic concepts, 5–6
  available solver software, 10–11
  basis vs. interior solution, 9
  chemical engineering, 37–46
    design and operations applications, 37
    model predictive control, 41–46
    production planning, 37–41
  complementarity conditions in SOCO vs., 116
  complexity, 8–9
  computational methods and software, 9–10
  and CVaR problems, 431–432
  distributional robustness, 348–350
  electrical engineering, 27–36
    communication networks, 36
    filter design, 28–30
    information and coding theory, 34–35
    norm optimization, 31–34
    pattern classification, 30–31
  financial engineering, 149–150
  general problem, 3–4
  and global optimization, 165
  integer optimization vs., 49, 51
  IPM extensions, 11
  and optimal control problems, 122, 125–129
  and polynomial optimization, 119
  for pooling problems, 212
  process systems engineering, 317
  and robust optimization, 337
  and semidefinite optimization, 108
  truss topology design, 13–25
    ground structure approach, 13–14
    limitations, 23, 25
    LO formulations, 16–19
    minimum compliance problem, 19–21
    numerical experiments, 22–25
    structural analysis of trusses, 15–16
  voxelwise worst-case roubustness via, 354–355
Linear optimization bounds, for spherical codes, 34
Linear phase filter design, 28–29
Linear placement methods, 34
Linear programming (LP) relaxation, 451
Linear quadratic regulator (LQR), 123–124
Linear relaxations, for pooling problem, 214–216
Line-search methods, 228
Liouville PDE, 127–128
Liouville's equation, 125
Lipschitz condition, 171
Lipschitz-continuous f, 513–514
Lipschitz functions, 171
Lipschitz optimization, 171–172
LIPSOL (solver), 11
Liquid natural gas (LNG) inventory routing, 82–86

LMIs (linear matrix inequalities), 110
l_1-norm optimization, 31–34
  in circuit placement problems, 33–34
  in robust approximation problems, 31–32
  in sparse optimization problems, 32–33
LNG (liquid natural gas) inventory routing, 82–86
LO. *See* Linear optimization
Local branching (LB) heuristic, 58, 286
Local holding costs, 449
Local minima
  for convex problems, 163
  and nonlinear optimization methods, 226, 251
  for quadratic problems, 166, 167
Local search approach, in healthcare applications, 102
Local solution methods
  for nonlinear optimization, 163, 222, 251
  for pooling problem, 212–214
Log-concave distribution, CC problems with, 388
LogicNet Plus, 88
Logic propositions, in GDP models, 316
Long-term development issues, 479, 491
Long-term planning, in electric power systems, 364–365
LOQO (solver), 11, 117, 234
Lorentz cone, 107
Loss function
  in decentralized supply chain optimization, 454
  in infinite-horizon problems, 448
  in newsvendor problem, 444
  overproduction, 401
  underproduction, 401–402
Loss-of-goodwill cost, 443, 445
Lost load, value of, 411
Lost sales, 443, 445
Lower bound
  in branch-and-bound method, 274
  of value function, 129
LP (linear programming) decoding techniques, 35
LP relaxation, 451
LP/NLP-based branch-and-bound approach, 278–279
LQR (linear quadratic regulator), 123–124

Macroscopic/microscopic approach, 70–71
MADS. *See* Mesh adaptive direct search
Magnitude filter design, 29
Main line railway systems, 66
Mali, delivery routing in, 489
Mangasarian–Fromowitz constraint qualification (MFCQ), 225
Marching cube algorithms, 520
Marginal benefit, in inventory modeling, 485
Marginal CVaR constraints, 432–435
Marginal risk contributions, 432
Marginal VaR constraints, 432–435
Marginal water valuation, 405–425
  hydroelectric generators with reservoirs, 405–406
  multiple-reservoir model, 416–419
  New Zealand electricity system, 419–425
  observed electricity prices vs. model outputs, 424–425
  single-reservoir model, 411–416
  social planning problem formulation, 406–411
Marginal water values, 409
Margin-based planning, 353
Mass, in aerospace systems, 249
Mass balances
  for distillation column, 239
  in physical building model, 261–262
Mass-equilibrium-summation-heat (MESH) equations, 238–239
Mass transit railway systems, 66, 75
Master model for nonlinear least squares, 532–533
Master problem, in Benders decomposition, 71
Matching problem, 52
Material balances, in physical building model, 261–262
Mathematical programs with complementarity constraints (MPCCs), 235
  column optimization with phase changes formulated as, 242–243
  formulation of distillation systems as, 240–241
  optimal design of distillation columns formulated as, 243–245
Mathematical programs with equilibrium constraints (MPECs), 465
Matrix-free approach to nonlinear optimization problems, 224
Maximal covering location problems, 453
Maximally complementary optimal solutions, 4
Maximization of expected portfolio return with upper bound on CVaR problem, 431
Maximization of expected portfolio return with upper bound on VaR problem, 428
Maximum clique problems, 165
Maximum comfort tracking strategy, 265, 268
Maximum independent set problems, 165
Maximum stiffness problem. *See* Minimum compliance problem
Maximum volume assumption, in truss topology design, 137
McCormick envelopes, 198–199, 214
MCS (solver), 506
MDO. *See* Multidisciplinary design optimization for aerospace systems
Mean-CVaR model, 431

Mean-variance portfolio optimization problem
  with convex quadratic constraints, 151–153
  robust optimization in, 155–157
  with transaction costs, 153–155
Mean-VaR model, 429
Medicine
  diagnosis and detection, 93–94
  discriminant analysis in, 96–99
  health logistics and operations, 95
  integer optimization applications, 93–103
  open challenges for, 102
  public health, 95
  solution strategies in, 102
  TCP-driven PET-image-guided treatment-planning model, 99–101
  treatment design in, 94–95
Mehrotra's predictor-corrector algorithm, 6
Merit functions, 228–229, 505
Mesh adaptive direct search (MADS), 500, 503, 504
MESH (mass-equilibrium-summation-heat) equations, 238–239
Metaheuristics
  for integer optimization, 57, 58
  for mixed-integer nonlinear optimization, 301, 327
  for optimal power flow problem, 192
MFCQ (Mangasarian–Fromowitz constraint qualification), 225
MH (moral hazard), 474
Microgeneration system, short-term planning in, 310–311
MIDO (mixed-integer dynamic optimization), 328
MILANO (solver), 289
Milano Underground System, 75
Military, min-max-min models in, 341–342
Milk banks, South African, 481
MILO. *See* Mixed-integer linear optimization
MILP. *See* Mixed-integer linear programming
Min-gen penalty, 460
Minima
  global minima
    in aerospace applications, 251
    and CLO problems with integer variables, 145
    for concave minimization problems, 164, 170, 172
    for convex vs. nonconvex problems, 163
    and termination of branch-and-bound algorithms, 170
  local minima
    for convex problems, 163
    and nonlinear optimization methods, 226, 251
    for quadratic problems, 166, 167
  in MINLP model of aircraft conflict avoidance, 297
Minimax stochastic optimization, 344
Minimization of CVaR problem, 431
Minimization of VaR problem, 428
Minimum compliance problem, 19–21, 137–138
Minimum Frobenius norm models, 497
Minimum volume problems, 16–18, 22–23
MINLO. *See* Mixed-integer nonlinear optimization
MINLP. *See* Mixed-integer nonlinear optimization
MINLPBB (solver), 289
Min-max-min models, 341–342
MINOS (solver), 235
MINOTAUR (solver), 289
MIP. *See* Mixed-integer programming
MIQCP (mixed-integer quadratically constrained programming), 273–274, 282
MISOCP (mixed-integer second-order cone programming), 274, 286
Michell beam, 22, 23
Mixed-integer dynamic optimization (MIDO), 328
Mixed-integer linear optimization (MILO)
  for aircraft conflict avoidance, 294–295. *See also* Mixed-integer linear programming (MILP)
  and chance constrained stochastic optimization, 389
  chemical engineering applications, 77–91
    chemical supply network optimization, 86–90
    LNG inventory routing, 82–86
    production planning for air separation plants, 78–82
  for generalized pooling problem, 212
  in optimal power flow problem, 199–202, 205
  process systems engineering applications, 317
  train dispatching applications, 68–70
Mixed-integer linear programming (MILP). *See also* Mixed-integer linear optimization (MILO)
  discretization, 213–214, 217
  piecewise relaxations, 215–216
  relaxations, 216–217
Mixed-integer nonlinear optimization (MINLO), 273–292
  air traffic management, 293–301
    aircraft conflict avoidance, 294–295
    automation in air traffic management, 293
    MINLP formulations, 295–300
    solution approaches, 300–301
  applications, 291–292
  branch-and-bound method, 274
  convex, 275–279
  enhancement techniques, 284–287
  expression of problem, 273
  for generalized pooling problem, 212
  general model, 316

nonconvex, 279–284
process systems engineering, 315–329
molecular computing, 329
planning and scheduling, 327–328
process control, 328–329
process synthesis, 317–327
superstructure, 315–316
types of models, 316–317
for SCUC problem, 191
short-term planning in cogeneration energy systems, 303–314
computational experiments, 310–314
data-driven vs. first-principles approaches, 304–305
described, 303–304
energy system variations, 305
MINLP formulations, 307–310
unit commitment vs., 305–307
solver software, 287–291
special cases, 273–274
Mixed-integer programming (MIP)
codes, 61–63
defined, 49
discriminant analysis via, 96–99
fixed charge problem in, 50
heuristics for, 57–58
impact of, 58–61
in medical diagnosis and detection, 94
Mixed-integer quadratically constrained programming (MIQCP), 273–274, 282
Mixed-integer second-order cone programming (MISOCP), 274, 286
Model-based trust-region methods, 505–506, 521
Model predictive control (MPC)
building automation, 259, 262–268
case studies, 266–268
constraints, 263–264
control strategies, 265–266
multiple objectives, 265
objective functions, 264
LO and QO models, 27, 41–46
MPC formulations, 42–43
plant automation structure, 44–46
variants and extensions, 43–44
nonlinear, 247, 317
Modes of operation, 78–79
Molecular computing, 317, 329
Moment sum of squares, 204
Monfalcone, Italy, 74–75
Monte Carlo sampling, 388–389
Moore's law, xxix
Moral hazard (MH), 474
MOSEK (solver), 10, 117
Motzkin–Straus QP, 165
MPC. *See* Model predictive control
MPCCs. *See* Mathematical programs with complementarity constraints
MPECs (mathematical programs with equilibrium constraints), 465
MSSLP (multistage stochastic linear programming) problems, 384–385
Multicolumn distillation systems, 246
Multicommodity flow formulation, 211–212
Multidisciplinary design optimization (MDO) for aerospace systems, 249–257
aerodynamic shape optimization, 252–254
aerostructural design optimization, 254–256
computational models, 250
described, 249–250
gradient computation, 251–252
optimization algorithms, 251
optimization problems, 250–251
satellite design and operation, 256–257
Multiechelon inventory optimization, 449–450, 463–465
Multigroup classification problems, 94
Multiobjective optimization, 506
Multiobjective studies, nonlinear optimization in, 260, 265
Multiperiod dispatch problem, 364
Multiperiod problems, 382–384
Multiple countries, vaccine issues involving, 472
Multiple-reservoir model for marginal water valuation, 416–419
Multistage robust optimization, 343, 364
Multistage stochastic linear programming (MSSLP) problems, 384–385
Multistage stochastic optimization model, 394
Mutation constraints, protein-DNA system, 178, 182
Myopic adaptive reoptimization, 343–344

Nash competition models, 464, 465
Natural disasters, 479
Natural gas industry
infrastructure impacted by, 466–467
inventory management for storage facilities in, 462
Neighborhood, 58
Neighborhood search
in integer optimization, 57, 58
large, 58
relaxation-enforced, 286
relaxation-induced, 58
variable, 212, 213, 301

Nelder–Mead algorithm, 498
NEOS Guide, 222
NEOS (Network-Enabled Optimization System) server, 119, 288
Nested decomposition method, 386, 389–391
Netherlands Railways, 58–59
Net load, worst-case, 362
Net load uncertainty, 360–362
Network design
  energy supply, 465–467
  and facility location problems, 450
Network-Enabled Optimization System (NEOS) server, 119, 288
Network flow model, convex cost, 487, 490–491
Network location models, 451
Network optimization, MILP models for, 86–90
Network utility maximization (NUM) problem, 36
NEWUOA (solver), 498, 503
Newsvendor problem, 381
  and decentralized supply chain optimization, 453
  for donated blood units in humanitarian applications, 484
  for fee-for-service contracts for brand-name drugs, 476
  and influenza vaccine supply chain, 470
  and multiechelon inventory optimization, 449
  as stochastic inventory optimization, 443–444
  with yield uncertainty, 448
Newton–Krylov method, 255
Newton's method, 227
Newton system, 6, 7
New Zealand electricity system, 419–425
Next Generation Air Transportation System (NextGen), 293
NGBD (nonconvex generalized Benders decomposition), 283
NLO. *See* Nonlinear optimization
Nodal formulation, for stochastic optimization, 386
Node callback, 63
No duality gap, polynomial optimal control problems with, 129
Noise analysis, 522–523
Noise-handling strategies, 522–525
Noise level reduction, 523–524
Noisy functions, in derivative-free optimization, 500–501
NOMAD (solver), 500
Nominal problem
  in robust optimization, 334
Nominal wind farm layout models
  performance of robust vs., 371–374
  problem formulation for, 369–370
Nonanticipativity condition, 364
Nonanticipativity constraints, 386
Nonconvex generalized Benders decomposition (NGBD), 283
Nonconvex MINLP, 279–284
  defined, 274
  domain propagation and bound tightening for, 281–282
  factorable programming for, 279–280
  piecewise-linear approximations and relaxations for, 283–284
  relaxations of structured sets for, 282–283
  solver software for, 288–291
  spatial branch-and-bound for, 280–281
Nonconvex nonlinear optimization problems, 222–223
Nonconvex optimization problems, computational complexity of, 167
Nonideal phase equilibrium, 246
Nonlinear blending, 40
Nonlinear branch-and-bound approach, 275–276, 279
Nonlinear classifiers, 31
Nonlinear constraints
  with general uncertainty set, 338–339
  for short-term cogeneration systems planning, 309–310
  uncertainty in, robust optimization with, 338–339
Nonlinearity, in refining planning problems, 40
Nonlinear least squares, 529–530, 532–533
Nonlinearly constrained optimization, 503–506
  extensions, 506
  model-based trust-region methods, 505–506
  relaxable constraints, 504–505
  unrelaxable constraints, 504, 505
Nonlinear model predictive control, 247, 317
Nonlinear optimal control, 121–133
  approximation results, 129–130
  control over set of initial conditions, 130–133
  history of optimal control, 121–122
  LP formulation, 125–129
  polynomial optimal control, 122–124
Nonlinear optimization (NLO), 221–235
  aerospace system applications, 250–251
  algorithm frameworks, 229–235
  availability of derivatives, 223
  building automation, 259–269
    building operations and inefficiencies, 260–261
    computational considerations, 268–269

HVAC system automation, 259
physical building model, 261–262
predictive control, 262–268
characteristics of problems, 222–224
convexity in, 163
convex vs. nonconvex problems, 222–223
distillation systems, 237–247
basic distillation model, 238–240
case studies, 241–245
described, 237–238
extensions, 245–247
MPCC formulation, 240–241
for equal-risk contribution portfolios, 158–159
extensions, 235
general problem statement, 221
interior-point methods, 233–235
line-search and trust-region globalization methods, 227–228
merit functions and filters, 228–229
Newton and quasi-Newton methods, 227
optimality conditions, 224–226
and polynomial optimization, 119
process systems engineering applications, 317
refinery planning problems, 41
sequential quadratic programming methods, 229–233
truss topology design, 16, 136–139
dual problem, 139
existence of solution, 137–139
primal problem, 137
and semidefinite optimization formulation, 143
voxelwise worst-case roubustness via, 354–355
for worst-case robustness, 352–354
Nonpolyhedral envelopes, 283
Non-Shannon-type inequalities, 35
Nonsmooth functions
linearly constrained optimization, 503
sampling along directions for, 503
unconstrained optimization, 499–500
worst-case complexity bounds, 501
No relaxation gap assumption, 125
Normal distribution, 388, 398, 429, 448
Norm optimization, 31–34
circuit placement, 33–34
robust approximation, 31–32
sparse optimization, 32–33
Norway, train dispatching in, 74
NOWPAC (solver), 506
NP-completeness, theory of, 52
NP-hard problem(s)
conic linear optimization, 113
facility location, 450, 451
global optimization, 166–167
integer optimization, 96, 99
inventory optimization, 442
mixed-integer nonlinear optimization, 274
optimal power flow problems as, 191, 203
pooling problem as, 207
in protein-DNA system design, 175
robust optimization, 343, 362
NUM (network utility maximization) problem, 36
Nurse scheduling, 95

OA technique. *See* Outer approximation technique
OBBT (optimality-based bound tightening), 281–282
Objective functions
building automation, 264
convex, 441, 444, 449
evaluation of, in TAO, 535–536
pooling problem, 209
Observed electricity prices, 424–425
Occupation measures, 125–128, 131–133
ODE (ordinary differential equation), Cauchy, 127–128
Offtake delays, 488–490
OMEGA technology, 208
One-degree-of-freedom cogeneration units, 305
On-hand inventory, 383, 440, 445, 476
Operating reserve markets, 462, 463
Operating room scheduling, 95
Operational planning, 393–394
OPF problem. *See* Optimal power flow problem
Opportunistic polling, 499
Optimal control. *See also* Polynomial optimal control problems (POCPs)
nonlinear, 121–133
approximation results, 129–130
control over set of initial conditions, 130–133
history of optimal control, 121–122
LP formulation, 125–129
polynomial optimal control, 122–124
polynomial, 122–124
examples of, 123–124
general description, 123
history of, 121–122
Optimal ordering policies, in healthcare, 473
Optimal policy, for marginal water values, 414–415
Optimal power flow (OPF) problem, 187–205
convex outer approximation for, 198–202
described, 187–188
example data for, 192–197
formulation for, 189–190
future research directions, 205

Lagrangian relaxation for, 202–203
linear approximation with direct current flow, 197–198
McCormick envelopes in, 198–199
moment sum of squares for, 204
OPF problem described, 187–188
piecewise-linear envelopes in, 199–202
problem statement for, 188
solution methods, 191–205
spatial branch-and-bound algorithm, 204–205
sufficient strong duality condition, 203–204
variants and extensions for, 190–191
Optimal reactive power flow (ORPF) problem, 191
Optimality-based bound tightening (OBBT), 281–282
Optimality conditions
in conic linear optimization, 115–116
for global optimization, 167–168
for nonlinear optimization, 224–226
Pareto robust, 340
Optimality tolerance, of branch-and-bound method, 274
OQNLP (solver), 290
Order-up-to level (decision variable), 445, 446
Ordinary differential equation (ODE), Cauchy, 127–128
ORPF (optimal reactive power flow) problem, 191
Outer approximation (OA) technique
for concave minimization problem, 170–171
convex, 198–202
for convex MINLP problems, 277
for optimal power flow problem, 198–202
Output, cost-sharing contracts based on, 471
Outsourcing of pharmaceutical production, 469–470
Overage cost, 381, 443
Overproduction demand constraints, 396
Overproduction loss function, 401

Parallel deterministic parameters, 62
Parallelism, in TAO, 535–536
Parallelizing DFO approaches, 506
Parallel opportunistic parameters, 62
Parallel processing, xxix–xxx
Parameterization, of uncertainty set, 339
Parent nodes, branch-and-bound tree, 275
Pareto front, 264
Pareto robust optimization paradigm, 340
Partial differential equations (PDEs)
in aerospace engineering, 250–252
direct methods for evaluating derivatives of, 252
discretization of three-dimensional, 224, 231
Liouville, 127–128
Partial-load penalty, 460
Partitioning of uncertainty, 342–343
PATHNLP (solver), 196
Pattern classification, 30–31
Pavement rehabilitation, 466
PcX (solver), 11
PDEs. *See* Partial differential equations
Peaking power generators, 460
Peaking premium, 460
Peano curves, 172
Penalties
exact penalty function, 228–229
Huber penalty function, 31
min-gen, 460
partial-load, 460
stockout, 380–381
sum-of-squares, 31
worst-case, 353–354
Penalty-steering methods for nonlinear optimization, 229
PENNON (solver), 235
Pennsylvania, infrastructure and energy industry in, 466
PENOPT solvers, 118
Periodic event-scheduling problem (PESP) constraints, 59
Periodic review
in dynamic economic lot sizing problem, 442–443
infinite-horizon problem with, 446
Perishable goods
in healthcare settings, 473
in humanitarian applications, 483–487
in newsvendor problem, 443
PESP (periodic event-scheduling problem) constraints, 59
PET (positron emission tomography)-image-guided treatment-planning model, 99–101
P-formulation, pooling problem, 209–210, 214, 215
PFV integrase enzyme, 182–184
constraints and force fields, 182–183
protein-DNA design results, 183–184
template generation, 182
Pharmaceutical capacity planning, 469–470
Pharmaceuticals
fail-to-supply contracts for generic drugs, 477–478
fee-for-service contracts for brand-name drugs, 475–477
global healthcare logistics for, 491
licensing contracts for new drugs, 474–475

Phase changes, distillation column optimization with, 242–243
Phase equilibrium, 237, 238, 246
Phase-shifting and tap-changing transformers, 190
Physical coupling of building control systems, 261
Pickup and delivery process, MIP for, 60
Piecewise-constant functions for uncertainty, 342–343
Piecewise-linear approximations, 283–284
Piecewise-linear envelopes, 199–202
Piecewise-linear outer estimators, 284
Piecewise-linear relaxations, 284
Pivot algorithms
  complexity of, 8
  for linear optimization, 5–6
  optimal basis solution from, 9
  for quadratic optimization, 7
Pivot rules, 5–6
Pivots, defined, 5
Piyavskii's algorithm, 172
Planning
  capacity planning
    energy industry, 457–458
    healthcare, 469–470
  in chemical plants, 393–394
  long-term planning in electric power systems, 364–365
  margin-based, 353
  MINLO and GDP applications, 327
  operational, 393–394
  production planning, 470–472
    air separation plants, 78–82
    healthcare, 470–472
    linear optimization, 37–41
  refinery planning, 37–41
    models, 327
    planning model extensions, 40–41
    process description and LO formulation, 38–40
  short-term planning in cogeneration energy systems, 303–314
    computational experiments, 310–314
    data-driven vs. first-principles approaches, 304–305
    described, 303–304
    energy system variations, 305
    MINLP formulations, 307–310
    unit commitment vs., 305–307
  social planning problems, 406–411
  supply chain planning model, 393–394
  TCP-driven PET-image-guided model, 99–101
  trajectory planning, 295
  treatment planning
    described, 346–348
    distributional robustness, 348–350
    integer optimization applications, 94–95
    probabilistic robustness, 350–352
    robust optimization, 346–355
    voxelwise worst-case roubustness, 354–355
    worst-case roubustness, 352–354
  types of models for, 317
  urban, xxxi
Planning horizon
  and adaptive robust UC model with net load uncertainty, 361
  for dynamic economic lot-sizing problem, 442
  and inventory management for energy storage facilities, 461
  and LNG inventory routing, 83–85
  and marginal water values, 407, 409
  for optimal power flow problem, 187, 188, 206
  and pharmaceutical capacity planning, 470
  for scenarios, 385
Plant automation, 44–46
Platelet inventory management, 473
P-median problems, 453
PMV (predicted mean vote), 263–264
PMV constrained strategy, 266, 268, 269
POCPs. *See* Polynomial optimal control problems
Pointed cone, 112
Poisson distribution, 444, 447, 486
Polar coordinates, 189–190
Policy, defined, 385
Polling
  linearly constrained optimization, 503
  probabilistic descent, 502
  unconstrained optimization, 498–499
Polyhedral annexation, 171
Polyhedral combinatorics, 52
Polyhedral constraints strategy, 266, 269
Polyhedral envelopes, 282
Polyhedral relaxations, 276–277
Polyhedral uncertainty set, 335
Polynomial models for unconstrained optimization, 497
Polynomial optimal control, 122–124
  examples of, 123–124
  general description, 123
  history of, 121–122
Polynomial optimal control problems (POCPs)
  approximation results for, 129–130
  with control over initial conditions, 130–133
  examples of, 123–124
  general description, 123
  LP problem formulation, 125–129
    dual problem, 129
    occupation measure, 126–128

primal problem, 128–129
relaxed controls, 125–126
Polynomial optimization, 119–120
Polynomial optimization problems (POPs), 119–121
Pooling, in refining planning problems, 40
Pooling problem, 207–217
blending problem vs., 207
computational advancements, 216–217
described, 207–208
formulation, 208–212
P-formulation, 209–210
PQ-formulation, 211
problem statement, 208–209
Q-formulation, 210
TP- and STP-formulations, 211
variants and extensions, 211–212
global solution methods, 214–216
local solution methods and heuristics, 212–214
variants and extensions, 211–212
POPs (polynomial optimization problems), 119–121
p-order cone, 112
Port delays, 487–489
Portfolio optimization problems
conic linear optimization models for, 151–153
typical formulation for, 149–150
Portfolio selection, 149
Positive duality gap, conic optimization with, 113–114
Positive semidefinite (PSD) matrices, 108
Positive semidefiniteness constraints, 56
PSD relaxations, 205
Positive spanning sets (PSSs), 498–499
Positron emission tomography (PET)-image-guided treatment-planning model, 99–101
POUNDERS (Practical Optimization Using No Derivatives for Sums of Squares) solver, 529–539
algorithm underlying, 533–535
and DFO described, 529–530
energy density functional calibration, 536–539
inputs, 536
smooth residual models, 530–533
Toolkit for Advanced Optimization software, 535–536
Power approximation, 446
Power generators, capacity certainty and volume flexibility of, 459–461
Power market competition, 461
Power system management, 457–461
efficient and responsive sourcing in capacity planning, 457–458
random capacity and volume flexibility, 459–461
Power system operations, decision-making problems in, 357–358
PPD (predicted percentage dissatisfied), 263–264
PQ-formulation, pooling problem, 211, 214–216
Practical Optimization Using No Derivatives for Sums of Squares solver. *See* POUNDERS
Praxair, 77–82
Predicted mean vote (PMV), 263–264
Predicted percentage dissatisfied (PPD), 263–264
Presolve technique, for MINLP problems, 284
Pressure control system, 260
Primal-dual approach for nonlinear optimization, 234–235
Primal heuristics, 285–286
Primal problem
in nonlinear optimization, 137
for optimal control applications, 128–129
in second-order cone optimization, 139–140
in semidefinite optimization, 108, 141
in truss topology design, 137, 139–141
Primal simplex method, 22–25
Primal simplex method pivot rules, 5–6
Primitive uncertainty sets, 342
Principal-agent problems, 474
Principal minors, 108
Prioritized usage, inventory modeling with, 485–487
Priority dispatch policy, 460–461
Private-sector facility location, 450
Probabilistic descent, 502
Probabilistic Markowitz model, 429
Probabilistic models, derivative-free optimization for, 502
Probabilistic robustness, 350–352
Probabilistically constrained stochastic optimization, 387
Probability of technical success (PTS), 474
Probing method, 282
Process control. *See also* Model predictive control (MPC)
LO and QO for, 37
MINLO and GDP applications, 328–329
types of models for, 317
Process flowsheet synthesis, 317–319
Processing time, 395–396, 450, 489
Process synthesis, 317–327
aggregated models, 317–318
distillation sequences, 323–324
heat exchange networks, 324, 325
process flowsheet synthesis, 318–319
reactor networks, 319–320
rigorous models, 318
shortcut models, 318

single distillation columns, 320–323
types of models for, 317
utility systems, 324–326
water networks, 326–327
Process systems engineering (PSE)
MINLO and GDP applications, 315–329
molecular computing, 329
planning and scheduling, 327–328
process control, 328–329
process synthesis, 317–327
superstructure, 315–316
types of models, 316–317
MIP in, 77
Process yields, refining, 40
Production planning
air separation plants, 78–82
healthcare applications, 470–472
linear optimization, 37–41
planning model extensions, 40–41
process description and LO formulation, 38–40
Production volume, 471
Progressive barrier method, 505
Projected aggregate production profiles, 393
Proper cone, 112
Proportional market impact cost model, 153–154
Proportional model. *See* Q-formulation
Protein-binding cavity alignment via DFO-VASP, 519–528
computational experiments, 525–527
DFO method, 521–522
electrostatic data, 521
noise-handling strategies for VASP, 522–525
protein specificities, 519–520
VASP method, 520
Protein-DNA sequence selection, 179–180
Protein-DNA system design, 175–185
biological applications of optimization, 175–176
energy metric, 181–182
fold specificity, 180–181
global optimization methods, 176–177
input parameters and constraints, 177–179
for PFV integrase enzyme, 182–184
protein-DNA sequence selection, 179–180
Protein families, 525–526
Protein specificities, 519–520
Pruning (fathoming), 169, 275
PSD (positive semidefinite) matrices, 108
PSD relaxations, 205
PSE. *See* Process systems engineering
Pseudocost branching, 285
PSSs (positive spanning sets), 498–499
PTS (probability of technical success), 474
Public health, 95
Public-sector facility location, 450, 453
Purchase costs, 440, 442, 445
pyOpt interface, 251

QCO (quadratically constrained optimization), 152–153
QCQO (quadratically constrained quadratic optimization) problem, 139, 211
Q-formulation, pooling problem, 210, 214, 215
QO. *See* Quadratic optimization
QP. *See* Quadratic optimization problem
Quadratically constrained optimization (QCO), 152–153
Quadratically constrained quadratic optimization (QCQO) problem, 139, 211
Quadratic functions, relaxations of, 282
Quadratic interpolation models, 530–531
Quadratic models for smooth functions, 497
Quadratic optimization (QO). *See also* Quadratic optimization problem
algorithmic concepts, 7
available solver software, 10–11
basis vs. interior solution, 9
chemical engineering, 37–46
design and operations applications, 37
model predictive control, 41–46
production planning, 37–41
complexity, 8–9
computational methods and software, 9–10
electrical engineering applications, 27–36
communication networks, 36
filter design, 28–30
information and coding theory, 34–35
norm optimization, 31–34
pattern classification, 30–31
financial engineering applications, 149
and global optimization, 165–166
IPM extensions, 11
for portfolio optimization problems, 151–152
process systems engineering applications, 317
Quadratic optimization problem (QP). *See also* Quadratic optimization
active-set solvers, 232–233
equality-constrained, 230–231
general, 4, 231–232
general purpose solvers, 233
SQP methods for, 229
Quadratic placement methods, 34
Quadratic problems, convexity of, 166–167
Quadratic unconstrained binary optimization (QUBO) problems, 164–165, 168
Quasi-Newton approximation, 227, 497

Radial basis functions (RBFs), 497–498
Radiation therapy

integer optimization, 94–95
robust optimization, 345–356
intensity-modulated radiation therapy, 345–346
LO for distributional robustness, 348–350
NLO for worst-case robustness, 352–354
scenario doses, 347–348
SOCO for probabilistic robustness, 350–352
treatment planning, 346–347
uncertainties, 347
voxelwise worst-case robustness, 354–355
Railway systems, dispatching in, 65–68
Railway timetables, 58–59
Railway transportation, 65
Random capacity, in power system operations, 459–461
Random directions, hidden constraint problems with, 515–517
Random-start approach, 525
Random yield, in vaccine planning, 471
RANS (Reynolds-averaged Navier–Stokes) equations, 253
RBFs (radial basis functions), 497–498
R&D (research and development), collaborative, 474–475
RdDS approach, 500, 503, 504
Reactive power planning (RPP) problem, 191
Reactor networks, 317, 319–320
Read command, MIP, 61
Realized scenarios, 334
Real options, 462
Real-time operation, in electric power systems, 364–365
Real-time optimization (RTO), 44–46, 317
Real-time pricing (RTP), 78
Reboilers
in distillation system optimization, 238, 242, 246, 247
in MINLP for single distillation column, 321–323
RECIPE heuristic, 286
Recourse-based robust optimization, 340–344
affine adjustable robust solutions from, 342
finite adaptability with, 342–343
fully adjustable robust solutions in, 340–341
min-max-min models in, 341–342
myopic adaptive reoptimization with, 343–344
Rectangular coordinates, 189–190
Reduced-cost bound tightening, 281–282
Reduced Hessian matrix, 231
Reduced-order models (ROMs), 318
Reduced-space methods
in aerospace systems, 250–251
for nonlinear optimization, 224, 230
Reference solutions, 58
Refinery planning, 37–41
models for, 327
planning model extensions, 40–41
process description and LO formulation, 38–40
Reformulation-linearization technique (RLT)
constraints in, 180
generating stronger relaxations with, 282
and PQ-formulation of pooling problem, 211
Regional trains, 72–74
Relative humidity control system, 260, 261
Relaxable constraints, 504–505
Relaxation-enforced neighborhood search (RENS), 286
Relaxation-induced neighborhood search (RINS), 58
Relaxations
in branch-and-bound method, 274
envelope-based, 214–215
Lagrangian relaxations
optimal power flow problem, 202–203
pooling problem, 215, 216
solving UFLPs, 452–453
supply network design for energy industry, 466
linear, for pooling problem, 214–216
linear programming, 451
MILP, 216–217
piecewise-linear, 284
polyhedral, 276–277
positive semidefinite, 205
of quadratic functions, 282
of structured sets, 282–283
Relaxed controls, LP problem with, 125–126
Reliability, of electric power systems, 357
Reliability branching, 285
Renewable energy. *See also* Wind farms
infrastructure and transportation issues related to, 466
intermittent sourcing of, 459–461
Renewable Identification Number (RIN) system, 465
RENS (relaxation-enforced neighborhood search), 286
Reorder point, 446
Research and development (R&D), collaborative, 474–475
Reserves, electric power system, 360
Reservoirs, hydroelectric generators with, 405–406
Residuals, modeling, 531–532
Resource allocation problems, 95, 96
Responsiveness–efficiency trade-off, in strategic sourcing, 457–458

Restoration methods, in derivative-free optimization, 505
Reverse mode algorithmic differentiation, 252
Reynolds-averaged Navier–Stokes (RANS) equations, 253
Rich direction sets, 512
Rigid templates, protein-DNA system, 178
Rigorous models, for process synthesis, 318
RINS (relaxation-induced neighborhood search), 58
RIN (Renewable Identification Number) system, 465
Risk-averse SO models, 389–391
Risk budgeting, 435
Risk management, 149
RiskMetrics framework, 428
Risk neutrality, 425
RLT. *See* Reformulation-linearization technique
Robust approximation, 31–32
Robust counterpart, 334
Robust counterpart optimization, 394
Robust mean-variance optimization, 155–157
Robust optimization, 333–344
  applicability, 333–334
  distributionally robust optimization, 344
  electric power systems, 357–365
    decision-making problems in power system operations, 357–358
    extensions, 362–364
    real-time operation and long-term planning, 364–365
    security-constrained unit commitment model, 359–362
  and linear optimization, 337
  Pareto paradigm, 340
  problem formulations, 334–340
  radiation therapy, 345–356
    intensity-modulated radiation therapy, 345–346
    LO for distributional robustness, 348–350
    NLO for worst-case robustness, 352–354
    scenario doses, 347–348
    SOCO for probabilistic robustness, 350–352
    treatment planning, 346–347
    uncertainties, 347
    voxelwise worst-case robustness, 354–355
  recourse-based robust optimization, 340–344
  and stochastic optimization, 397–400, 403–404
  train dispatching applications of, 66
  with uncertainty in linear constraints, 335–338
  with uncertainty in nonlinear constraints, 338–339
  uncertainty set parameterizations, 339
  wind farm layout, 367–375
    history of layout optimization, 367–368
    performance of nominal vs. robust models, 371–374
    problem formulations, 369–371
    wake models, 368–369
Robust portfolio selection, 156–157
Robust problems, 334
Robust solutions
  adjustable, 340–342
  affine adjustable, 342
  defined, 334
  fully adjustable, 340–341
Robust wind farm layout models
  performance of nominal vs., 371–374
  problem formulation for, 370–371
Rolling stock scheduling, 59
ROMs (reduced-order models), 318
ROSA system, 59
RosettaDock, 181
Rounding heuristic, 286
Rounds, of cuts, 56
Route optimization, 60
Routes, train, 67
RPP (reactive power planning) problem, 191
(r,Q) policy, 446, 447
RTO (real-time optimization), 44–46, 317
RTP (real-time pricing), 78
Run/optimize command, MIP, 61

SA (stochastic approximation), 381–382, 390
SAA (sample average approximation), 382, 390
SABR (South African Breastmilk Reserve), 481
Safety-first optimization problem, 429
Sample average approximation (SAA), 382, 390
Sampling
  in linearly constrained optimization, 502–503
  for smooth functions, 496–499
Sampling error, 424
Satellites, 256–257
SBB (solver), 289
SCED (security-constrained economic dispatch) problem, 191
Scenario-based models, 153, 401–404
Scenario decomposition, 386, 389, 391
Scenario doses, 347–348
Scenario trees, 385, 387, 407–408
Scenarios, 334, 385, 386
Scheduling
  in healthcare, 95
  integer optimization applications, 95
  MINLO and GDP applications, 328
  models for, 317
  in refinery planning, 40, 41
  train, 68

Schur complement theorem, 141, 142
SCIP (solver), 290, 313–314
SCUC model. *See* Security-constrained unit commitment model
SDDP (stochastic dual dynamic programming), 406
SDDP algorithm, 416–419, 424–425
SDO. *See* Semidefinite optimization
SDPA (solver), 118
SDPLR (solver), 118
SDPNAL (solver), 118
SDPT3 (solver), 117
Search
  convex hull, 213–214
  coordinate, 509–511
  direct-search methods
    linearly constrained optimization, 502–503
    nonlinearly constrained optimization, 504
    probabilistic descent, 502
    unconstrained optimization, 498–499
    worst-case complexity bounds, 501–502
  generalized pattern search, 499
  line-search methods, 228
  local search approach, 102
  mesh adaptive direct search, 500, 503, 504
  neighborhood search
    in integer optimization, 57, 58
    large, 58
    relaxation-enforced, 286
    relaxation-induced, 58
    variable, 212, 213, 301
  tabu, 57
Search direction sets, 511–512
Search step, in DFO algorithms, 506
SEC (Securities and Exchange Commission), 475
Second-order cone optimization (SOCO)
  and chance constrained stochastic optimization, 429–430
  and conic optimization, 110–111
  filter design, 29–30
  financial engineering applications, 150–160
    equal-risk contribution portfolios, 157–160
    portfolio optimization problems, 151, 153
    transaction costs with market impact, 153–155
  optimality conditions for, 116
  for probabilistic robustness, 350–352
  truss topology design, 139–141
    dual problem, 140–141
    primal problem, 139–140
    reformulation of problems with integer variables, 145–147
Securities and Exchange Commission (SEC), 475
Security-constrained economic dispatch (SCED) problem, 191
Security-constrained unit commitment (SCUC) model, 191, 359–362
  computational study, 361–362
  conservativeness of, 363–364
  with corrective actions, 363
  and deterministic model, 359–360
  extensions, 362–364
  robust model with net load uncertainty, 360–361
  solution method, 361–362
SeDuMi (solver), 11, 117
Self-dual embedding model, 8
Self-scaled cones, 112
Selling season, 443
Semidefinite optimization (SDO). *See also* Second-order cone optimization (SOCO)
  in conic linear optimization, 107–110
  defined, 107
  examples, 109–110
  financial engineering applications, 150, 160
  generating stronger relaxations with, 282–283
  optimality conditions, 115–116
  for optimal power flow problem, 203–204
  for polynomial optimization problems, 119–121
  with positive duality gap, 113–114
  and robust optimization, 342
  software, 118
  standard formulation, 108
  truss topology design, 141–143
    dual problem, 142–143
    nonlinear optimization formulation, 143
    primal problem, 141
  with weak infeasibility, 114
SEN (state equipment network) model, 323
Sensitivity analysis, 374, 441
Separable functions, 279
Separation maneuvers, aircraft, 294, 295, 298
Separations, models for, 317
Sequentially convexifiable programs, 55
Sequential quadratic programming (SQP)
  composite step-based, 505
  with nonlinear branch-and-bound, 279
  nonlinear optimization, 229–233
    active-set QP solvers, 232–233
    active-set SQP, 224
    equality-constrained NLO problems, 230–231
    general NLO problems, 231–232
    general purpose solvers, 233
Sequential synthesis method, 324
Serial systems, 449–450
Serine protease superfamily, 525, 526
SESAR (Single European Sky ATM Research), 293

Set-back relaxation strategy, 265–268
Set covering location problems, 453
Set-partitioning problem, 51
Set recovering problems, 51
Setup costs. *See* Fixed costs
Setup errors, in radiation therapy, 353–354
Shifting bottleneck procedure, 57
Shipment routing, in biofuel production, 466
Shortages, drug, 477–478
Shortcut models for process synthesis, 318
Shortest-path problem, 442–443
SHORTREC (Tactical Planning in Pickup and Delivery) program, 60
Short-term planning in cogeneration energy systems, 303–314
  computational experiments, 310–314
  data-driven vs. first-principles approaches, 304–305
  described, 303–304
  energy system variations, 305
  MINLP formulations for, 307–310
  unit commitment vs., 305–307
Sifting method, 22–25
Simplex gradients, 500, 512
Simplex sets, 498
Simultaneous synthesis method, 324
Single European Sky ATM Research (SESAR), 293
Single-period inventory model, 381
Single-reservoir model for marginal water valuation, 411–416
  Stage and Larsson vs. discounting methods, 411–413
  with thermal generation, 413–416
Single-server model assumption, 489
Single-stage robust solutions, 340
Site selection, wind farm, 367
Slater's constraint qualification, 114–115
Slave problem, in Benders decomposition, 71
SLP (successive linear programming) techniques, 212
Smooth functions, 496–499
Smoothing functions, 500
Smooth problems, NLO problems as, 223
Smooth residual models, 530–533
  master model for nonlinear least squares, 532–533
  modeling residuals in DFO, 531–532
  quadratic interpolation models, 530–531
SO. *See* stochastic optimization
SNOPT (solver), 196, 233, 251
Socially optimal demand, 472
Social planning problem formulation, 406–411
Social welfare, 470, 472, 477, 478
SOCO. *See* Second-order cone optimization
Solve callback, 63
SoPLex (solver), 10
SOS2 (special-ordered sets of type 2), 284
SOSTOOLS (software), 120
Sources, in STP-formulation, 211
South Africa, breast milk bank in, 480–483
South African Breastmilk Reserve (SABR), 481
South Dakota, infrastructure and energy industry in, 466
Space-filling curves, 172
Sparse optimization problems, 32–33
Sparse solution recovery theory, 497
Sparsity
  of building automation NLO problems, 268, 269
  and constrained optimization problems, 224
  of Hessian, 497
  and reduced-space approach, 224, 230
Spatial branch-and-bound
  for nonconvex MINLP, 280–281
  for optimal power flow problem, 204–205
  piecewise-linear relaxations with, 284
Spatial branching, 280
Spatial location equilibrium, 464
Special-ordered sets of type 2 (SOS2), 284
Spectral factorization method, 29
Spectral mask constraints, 29
Spherical codes, 34
SQP. *See* Sequential quadratic programming
SSP (stochastic social planning) problems, 407–411
(*s*,*S*) policy, 445–446
Stability enhancement
  MPC formulations for, 44
  and wind farm layout optimization, 372–374
Stackelberg game model, 454, 464–465
Stage and Larsson method
  for single-reservoir model, 411–412
  with thermal generation, 413–414
Stages, inventory chain, 449
Stagewise independent data, 384
Standalone risk approach, 432
Standard robust optimization, 341
State equipment network (SEN) model, 323
States, wind, 368
State-task-network (STN) model, 77, 323, 395
State variables, 250–254
Statically determinate structures, 18
Static stochastic optimization, 380–382
Stationary interval property, 440
STATIONS (solver), 59
Stations, railway, 66, 74
Statistics-based approaches for noisy functions, 501

Stavanger–Moi line, 74
Steepest descent method, 227
Stencil failure, 509
Stereotactic radiation, 94
STN model. *See* State-task-network model
Stochastic approximation (SA), 381–382, 390
Stochastic control, 125–126
Stochastic decomposition, 391
Stochastic dual dynamic programming (SDDP), 406
Stochastic dynamic programming model, 461, 462, 472
Stochastic failures, 488–489
Stochastic integer problems, 389
Stochastic optimization (SO), 379–391
  chance constrained, 387–389
  chemical engineering, 393–404
    CVaR-based method, 401–404
    operational planning in chemical plants, 393–394
    problem statement, 394–397
    robust optimization method, 397–400, 403–404
  and distributionally robust optimization, 344
  dynamic, 382–387
  extensions, 389–390
  history, 390–391
  inventory optimization, 443–448
    finite-horizon problem, 445–446
    infinite-horizon problem, 446–448
    newsvendor problem, 443–444
    supply uncertainty, 448
  investment portfolio construction, 427–435
    CVaR models, 430–432
    financial optimization, 427
    with marginal VaR and CVaR constraints, 432–435
    VaR models, 428–430
  marginal water valuation, 405–425
    hydroelectric generators with reservoirs, 405–406
    multiple-reservoir model, 416–419
    New Zealand electricity system, 419–425
    observed electricity prices vs. model outputs, 424–425
    single-reservoir model, 411–416
    social planning problem formulation, 406–411
  static, 380–382
  train dispatching applications of, 66
  uncertain parameters, 379
Stochastic programming. *See* Stochastic optimization
Stochastic social planning (SSP) problems, 407–411
Stockout costs, 443, 445, 447, 448, 453
Stockout penalties, 380–381
Stockouts, 84, 440–444
Storage conversion loss, 462
Storage efficiency, 462
STP-formulation, pooling problem, 211, 214, 215
Strategic behavior
  by healthcare consumers, 471–472
  and marginal water values, 425
Strategic sourcing, 457–458
Stress limits, 16
Strict complementarity, 226
Strong duality condition
  for conic optimization, 113
  for optimal power flow problem, 203–204
  and solution of adaptive robust model, 361–362
Strong duality theorem, 3–4
Structural engineering, xxx
Structural optimization, 13
Structural topology optimization, 13
Structured sets, relaxations of, 282–283
Subgradient optimization, 452
Subliminal control, 294
Substitution, at healthcare facilities, 473
Successive approximation techniques, 170–171
Successive linear programming (SLP) techniques, 212
Successive partitioning, 169
Successive underestimation methods, 171
Sufficient strong duality condition, 203–204
SUmb flow solver, 253
Sum of squares, moment, 204
Sum-of-squares certificate approach, 119–121
Sum-of-squares penalty, 31
Superpositions, protein, 519–520, 526–527
Superstructure optimization, 315–316, 319–320
Supply chain contracting, 473–478
Supply chain coordination, 453–455
Supply chain engineering
  chance-constrained stochastic optimization in, 387
  dynamic stochastic optimization in, 382–384
  static stochastic optimization in, 380–381
  two-stage model for, 393–394
Supply Chain Guru, 88
Supply chain network design, 465–467
Supply chain optimization, 439–455
  decentralized supply chains, 453–455
  energy industry applications, 457–467
    feedstock procurement, 463–465
    inventory management, 461–463

power system management, 457–461
supply network design, 465–467
facility location problems, 450–453
healthcare applications, 469–478
capacity planning, 469–470
inventory management, 473
production planning, 470–472
supply chain contracting, 473–478
humanitarian applications, 479–491
bottlenecks in transportation networks, 487–491
challenges, 479–480
facility location, 480–483
future perspectives, 491
inventory modeling, 483–487
and inventory optimization, 439–450
MIP for, 60–61
mixed-integer linear optimization models for, 86–90
Supply chains, decentralized, 453–455
Supply disruptions, 448, 477, 478
Supply uncertainty, 448, 459–461
Support vector machines, 30, 98
Surrogate models, 318
Sustainable buildings, 259
Symmetric cones, 112, 117–118
Symmetry, MINLP problems with, 285

Tabu search, 57
Tactical-level aircraft conflict avoidance, 294–295
Tactical Planning in Pickup and Delivery (SHORTREC) program, 60
Take-off gross weight, 254–256
Tandem queuing model, 488–489
TAO (Toolkit for Advanced Optimization) software, 535–536
Targeting, reactor network, 320
Taylor-like conditions, 531
TCP. *See* tumor control probability (TCP)-driven PET-image-guided treatment-planning model, 99–101
TE (tracking error) constraints, 152–153
Temperature control system, 260, 261
Terminal nodes, in TP-formulation, 211
Terminal value function, 445
Termination of branch-and-bound algorithm, 170
Termination tests, 226
Ternary mixture, distillation of, 242–243
Thermal comfort constraints, 263–264
Thermal generation, 413–416
Thermally coupled systems, 323–324
Threshold policy for marginal water values, 414
Time configurations, for aircraft, 298
Time-indexed formulations for train dispatching, 69
Time-of-use (TOU) rates, 78
Time-sensitive electricity prices, 78–82
Time-space network representation, 83
Timetables, railway, 58–59, 67
Time value of money, 445
Time-window improvement heuristic, 85
Time windows, in aircraft conflict avoidance, 298–299
TMSs (train management systems), 67–68, 72–75
TNT Express, 60–61
TNT Express Routing and Network Scheduling (TRANS) program, 60
Toolkit for Advanced Optimization (TAO) software, 535–536
Topology design. *See* Truss topology design
Total mass balance, distillation column, 239
Total probability, 385
Total variation regularization, in image deblurring, 32
Total water networks (TWNs), 326–327
TOU (time-of-use) rates, 78
TP-formulation, pooling problem, 211, 214
Traffic equilibrium, 466
Train dispatching, 65–75
basic MILP models, 68–70
decomposition principle, 70–72
dispatching in railway systems, 65–68
real-life implementation, 72–75
Train-dispatching problem, 67–70
Train management systems (TMSs), 67–68, 72–75
Trajectory planning, aircraft, 293, 294
Transaction costs, with market impact, 153–155
Transformers, phase-shifting and tap-changing, 190
Transmission network planning problem, 365
Transportation congestion, 465–467
Transportation costs
in biofuel supply chain design, 466
for breast milk bank, 480–483
and facility location, 451, 480–483
Transportation networks
bottlenecks in, 487–491
delay modeling in delivery routing, 489–491
port and corridor delays in, 487–489
TRANS (TNT Express Routing and Network Scheduling) program, 60
Traveling salesman problem (TSP), 52–53
Treatment planning
integer optimization applications in, 94–95
robust optimization, 346–355
described, 346–348
distributional robustness, 348–350
probabilistic robustness, 350–352
voxelwise worst-case robustness, 354–355

worst-case robustness, 352–354
TCP-driven PET-image-guided model, 99–101
Tree networks, 450
branch-and-bound tree, 275
scenario trees, 385, 387, 407–408
Trento–Bassano del Grappa line, 72–73
Trondheim–Dombås line, 74
Truncation, in finite-horizon problem, 445
Trusses, structural analysis of, 15–16
Truss notation, 135–136
Truss topology design
conic linear optimization models, 135–147
applications, 144
integer variables, problems with, 145–147
nonlinear optimization formulation, 136–139
SDO formulation, 141–143
SOCO formulation, 139–141
truss notation, 135–136
vibration constraints, 144–145
linear optimization, 13–25
ground structure approach, 13–14
limitations, 23, 25
LO formulations, 16–19
minimum compliance problem, 19–21
numerical experiments, 22–25
structural analysis of trusses, 15–16
Trust-funnel methods, 505
Trust-region methods
derivative-free optimization
linearly constrained optimization, 503
noisy functions, 501
nonlinearly constrained optimization, 505–506
probabilistic models, 502
smooth functions, 496–498
unconstrained optimization, 496–498, 501, 502
model-based trust-region methods
derivative-free optimization, 505–506
in protein-binding cavity volumetric alignment, 521
for nonlinear optimization, 228
TSP (traveling salesman problem), 52–53
Tumor control probability (TCP)-driven PET-image-guided treatment-planning model, 99–101
TURNI (software), 59
TWNs (total water networks), 326–327
Two-degrees-of-freedom cogeneration units, 305
Two-ship improvement heuristic, 85
Two-stage adaptable optimization problem, 340–341
Two-stage approach to protein-DNA system design, 176
Two-stage fully adaptive robust optimization model
computational study, 362
for electric power systems, 360–364
extensions of, 362–364
formulation, 360–361
solution method, 361–362
Two-stage stochastic linear optimization approach, 394
Two-stage stochastic planning under uncertainty model, 393
Two-stage stochastic supply chain planning model, 393–394
Two-station, tandem queuing model, for port and corridor delays, 488–489
Type-1 service level, 444

UC (unit commitment), 359
UFLPs (uncapacitated fixed-charge location problems), 451–453
Uncapacitated fixed-charge location problems (UFLPs), 451–453
Uncertain parameters, stochastic optimization with, 379
Uncertainty(-ies)
budget of, 361
capacity, 448
demand, 393–394, 397
distributional, 368
in electric power systems, 358
hierarchical approach to planning and scheduling under, 394
lead-time, 448
in linear constraints, 335–338
and MILP models, 91
net load, 360–362
in nonlinear constraints, 338–339
partitioning of, 342–343
piecewise-constant functions for, 342–343
in radiation therapy, 347
in refinery planning problems, 40–41
and robust optimization, 333
supply, 448, 459–461
two-stage stochastic planning under, 393
in utility capacity planning problem, 458
in wind farm layout optimization, 368, 370
yield, 448
Uncertainty set(s)
budgeted, 361
cardinality-constrained, 336–337
convex, 337–338
defined, 334
for electric power application, 361
ellipsoidal, 335–336, 338, 339

general, 338–339
parameterizations of, 339
polyhedral, 335
primitive, 342
for wind farm layout optimization, 371
Unconstrained optimization
derivative-free optimization, 496–502
noisy functions, 500–501
nonsmooth functions, 499–500
probabilistic models, 502
smooth functions, 496–499
worst-case complexity and global convergence, 501–502
nonlinear optimization, 223–224, 226–227
protein-binding cavity volumetric alignment, 521–522
Underage cost, 381, 443
Undercover heuristic, 286
Underproduction demand constraints, 396
Underproduction loss function, 401–402
UNEDF (Universal Nuclear Energy Density Function) low-energy physics project, 536–539
Uniform convergence, 130, 132–133
Unit commitment (UC). *See* UC (unit commitment) problems
UC (unit commitment) problems
in cogeneration energy systems, 304–305
and power system operations, 459
robust optimization for, 358–362
security-constrained, 191
short-term planning problems vs., 305–307
Universal Nuclear Energy Density Function (UNEDF) low-energy physics project, 536–539
Unrelaxable constraints
derivative-free optimization with, 504, 505
and POUNDERS, 535
UN World Food Programme, 488
Upper bound
in branch-and-bound method, 274
on CVaR, 431
on VaR, 428
Urban planning, xxxi
Usage policy, 484–487
User cut callback, 63
Utility, in vaccine supply chain problem, 471
Utility systems, MINLO and GDP for, 324–326

Vaccine production planning, 470–472
Vaccines, 96, 470–472
Value-at-risk (VaR), 149, 150, 394
CVaR vs., 431
for investment portfolio construction, 428–430
marginal VaR contribution for assets, 433–434
Value function, 129
Value of lost load, 411
Valve trains, automotive, 508
VaR. *See* Value-at-risk
Variable costs, 359
Variable-depth interchange heuristic, 57
Variable neighborhood search (VNS), 212, 213, 301
VASP. *See* Volumetric analysis of surface properties
Velocity regulation, aircraft, 294
Vertex cover problem, 52, 453
Vibration constraints, 144–145
Violation transfer, 281, 285
Virtual constraints. *See* Hidden constraints
VNS. *See* Variable neighborhood search
Volume flexibility, of power generators, 459–461
Volumetric analysis of surface properties (VASP). *See also* DFO-VASP protein-binding cavity alignment
described, 520
noise-handling strategies for, 522–525
Voxels, 347
Voxelwise worst-case robustness, 354–355

Wagner–Whitin algorithm, 442
Wagner–Whitin problem, 442–443
Wait-and-see decisions
in marginal water value calculations, 413, 419, 424
robust optimization for, 340–341
Wake models, 368–369
Wake region, wind turbine, 367, 368
Warehouse location problem, 51
Warm-start approach, 524–525
Warm-start feature, of QP solvers, 232
Wastewater treatment networks (WWTNs), 326–327
Water networks, 317, 326–327
Water resource policy, 508
Water treatment network problem, 216
Water-using networks (WUNs), 326–327
Water valuation, 405–425
and hydroelectric generators with reservoirs, 405–406
multiple-reservoir model for, 416–419
in New Zealand electricity system, 419–425
observed electricity prices vs. model outputs for, 424–425

single-reservoir model of, 411–416
social planning problem formulation for, 406–411
Watson project, xxx
WCC bounds. *See* Worst-case complexity bounds
Weak duality condition, 113
Weak infeasibility, conic optimization with, 114
Weber problem, 450–451
Weiszfeld procedure, 451
Welfare-maximizing solution to SSP, 410
Wholesale electricity markets, 405
Wholesale price contracts, 454
Wholesale prices, 454, 455
Wind direction, 368, 371
Wind farms
layout optimization, 367–375
history, 367–368
performance of nominal vs. robust models, 371–374
problem formulations, 369–371
wake models, 368–369
prevalence of, 367
Wind states, 368
Wing box, 256
Wing design
aerodynamic shape optimization, 252–254
aerostructural design optimization, 254–256
Working set, for active-set QP solvers, 232
Worst-case complexity (WCC) bounds
in derivative-free optimization, 501–502
in supply chain optimization, 448
Worst-case dose distributions, 354–355
Worst-case net load, 362
Worst-case penalty, 353–354
Worst-case robustness, 352–355
Worst-case scenarios, 333
WUNs (water-using networks), 326–327
WWTNs (wastewater treatment networks), 326–327

XPRESS (solver), 10, 82
Xpress-SLP (solver), 289

YALMIP modeling language, 119
Yes-no constraints, 507. *See also* Hidden constraints
Yield optimization problem, 508
Yield uncertainty, 448
Young measure. *See* Relaxed control

Zero-inventory ordering (ZIO) property, 440, 442
Zero-order methods, 169
z transformations, in CVaR method, 401