
APPENDIX A

Details of Glass Property Constraints

NOTATION

C_1	Bound for Crystal1 – 3.0
C_2	Bound for Crystal2 – 0.08
C_3	Bound for Crystal3 – 0.225
C_4	Bound for Crystal4 – 0.18
C_5	Bound for Crystal5 – 0.18
k_{\min}	Lower limit for conductivity – 18
k_{\max}	Upper limit for conductivity – 50
μ_{\min}	Lower limit for viscosity (PaS) – 2.0
μ_{\max}	Upper limit for viscosity (PaS) – 10.0
D_{\max}^{PCT}	Max release rate (product consistency test) (g per m ²) – 10.0
D_{\max}^{MCC}	Max release rate (materials characterization center) (g per m ²) – 28.0
μ_a^i	Linear coefficients of viscosity model
μ_b^{ij}	Cross term coefficients of viscosity model
k_a^i	Linear coefficients of electrical conductivity model
k_b^{ij}	Cross term coefficients of electrical conductivity model
Dp_a^i	Linear coefficients of durability (PCT) model (for Boron)
Dp_b^{ij}	Cross term coefficients of durability (PCT) model for Boron
Dm_a^i	Linear coefficients of durability (MCC) model (for Boron)
Dm_b^{ij}	Cross term coefficients of durability (MCC) model (for Boron)

1. Component Bounds:

- $0.42 \leq p^{(\text{SiO}_2)} \leq 0.57$
- $0.05 \leq p^{(\text{B}_2\text{O}_3)} \leq 0.20$
- $0.05 \leq p^{(\text{Na}_2\text{O})} \leq 0.20$
- $0.01 \leq p^{(\text{Li}_2\text{O})} \leq 0.07$
- $0.0 \leq p^{(\text{CaO})} \leq 0.10$
- $0.0 \leq p^{(\text{MgO})} \leq 0.08$

- g) $0.02 \leq p^{(\text{Fe}_2\text{O}_3)} \leq 0.15$
 h) $0.0 \leq p^{(\text{Al}_2\text{O}_3)} \leq 0.15$
 i) $0.0 \leq p^{(\text{ZrO}_2)} \leq 0.13$
 j) $0.01 \leq p^{(\text{other})} \leq 0.10$

2. Five glass crystallinity constraints:

- a) $p^{(\text{SiO}_2)} > p^{(\text{Al}_2\text{O}_3)} * C_1$
 b) $p^{(\text{MgO})} + p^{(\text{CaO})} < C_2$
 c) $p^{(\text{Fe}_2\text{O}_3)} + p^{(\text{Al}_2\text{O}_3)} + p^{(\text{ZrO}_2)} + p^{('Other')} < C_3$
 d) $p^{(\text{Al}_2\text{O}_3)} + p^{(\text{ZrO}_2)} < C_4$
 d) $p^{(\text{MgO})} + p^{(\text{CaO})} + p^{(\text{ZrO}_2)} < C_5$

3. Solubility Constraints:

- a) $p^{(\text{Cr}_2\text{O}_3)} < 0.005$
 b) $p^{(\text{F})} < 0.017$
 c) $p^{(\text{P}_2\text{O}_5)} < 0.01$
 d) $p^{(\text{SO}_3)} < 0.005$
 e) $p^{(\text{Rh}_2\text{O}_3+\text{PdO}+\text{Ru}_2\text{O}_3)} < 0.025$

4. Viscosity Constraints:

- a) $\sum_{i=1}^n \mu_a^i * p^{(i)} + \sum_{j=1}^n \sum_{i=1}^n \mu_b^{ij} * p^{(i)} * p^{(j)} > \log(\mu_{\min})$
 b) $\sum_{i=1}^n \mu_a^i * p^{(i)} + \sum_{j=1}^n \sum_{i=1}^n \mu_b^{ij} * p^{(i)} * p^{(j)} < \log(\mu_{\max})$

5. Conductivity Constraints:

- a) $\sum_{i=1}^n k_a^i * p^{(i)} + \sum_{j=1}^n \sum_{i=1}^n k_b^{ij} * p^{(i)} * p^{(j)} > \log(k_{\min})$
 b) $\sum_{i=1}^n k_a^i * p^{(i)} + \sum_{j=1}^n \sum_{i=1}^n k_b^{ij} * p^{(i)} * p^{(j)} < \log(k_{\max})$

6. Dissolution rate for boron by PCT test (DissPCTbor):

$$\sum_{i=1}^n Dp_a^i * p^i + \sum_{j=1}^n \sum_{i=1}^n Dp_b^{ij} * p^{(i)} * p^{(j)} < \log(D_{\max}^{\text{PCT}})$$

7. Dissolution rate for boron by MCC test (DissMCCbor):

$$\sum_{i=1}^n Dm_a^i * p^i + \sum_{j=1}^n \sum_{i=1}^n Dm_b^{ij} * p^{(i)} * p^{(j)} < \log(D_{\max}^{\text{MCC}})$$

Waste Composition Data

Comp.	Fractional Composition of Wastes						
	AY-102	AZ-101	AZ-102	SY-102	SY-101	SY-103	B-103
SiO ₂	0.072	0.092	0.022	0.020	0.000	0.019	0.011
B ₂ O ₃	0.026	0.000	0.006	0.003	0.000	0.000	0.000
Na ₂ O	0.105	0.264	0.120	0.154	0.300	0.230	0.100
Li ₂ O	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CaO	0.061	0.012	0.010	0.030	0.007	0.006	0.000
MgO	0.040	0.000	0.003	0.012	0.000	0.001	0.000
Fe ₂ O ₃	0.328	0.323	0.392	0.133	0.000	0.039	0.155

	Fractional Composition of Wastes						
Comp.	AY-102	AZ-101	AZ-102	SY-102	SY-101	SY-103	B-103
Al ₂ O ₃	0.148	0.157	0.212	0.318	0.659	0.546	0.214
ZrO ₂	0.002	0.057	0.063	0.002	0.000	0.001	0.000
Other	0.217	0.096	0.173	0.328	0.034	0.159	0.520
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Cr ₂ O ₃	0.016	0.007	0.005	0.089	0.002	0.116	0.000
F	0.006	0.001	0.001	0.005	0.002	0.001	0.000
P ₂ O ₅	0.042	0.001	0.021	0.088	0.013	0.005	0.037
SO ₃	0.001	0.018	0.009	0.027	0.005	0.002	0.007
NobMet	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mass	59772	40409	143747	359609	167510	185990	6170

	Fractional Composition of Wastes $w^{(i)}/g^{(i)}$						
Comp.	BY-104	BY-110	C-103	C-105	C-106	C-108	C-109
SiO ₂	0.030	0.040	0.412	0.359	0.437	0.001	0.001
B ₂ O ₃	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Na ₂ O	0.082	0.089	0.006	0.012	0.014	0.010	0.007
Li ₂ O	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CaO	0.141	0.046	0.041	0.044	0.046	0.000	0.737
MgO	0.000	0.000	0.028	0.026	0.031	0.000	0.000
Fe ₂ O ₃	0.067	0.051	0.338	0.064	0.214	0.206	0.003
Al ₂ O ₃	0.344	0.462	0.057	0.372	0.168	0.693	0.013
ZrO ₂	0.007	0.003	0.043	0.004	0.008	0.032	0.000
Other	0.330	0.309	0.075	0.119	0.082	0.058	0.238
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Cr ₂ O ₃	0.000	0.000	0.002	0.005	0.004	0.002	0.000
F	0.001	0.001	0.000	0.000	0.000	0.000	0.000
P ₂ O ₅ 0.016	0.022	0.013	0.012	0.031	0.047	0.003	0.000
SO ₃	0.002	0.003	0.000	0.002	0.000	0.000	0.000
NobMet	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mass	155473	103492	85211	207127	367165	46919	53271

	Fractional Composition of Wastes						
	C-111	C-112	S-102	SX-106	TX-105	TX-118	U-107
SiO ₂	0.002	0.001	0.000	0.033	0.010	0.060	0.008
B ₂ O ₃	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Na ₂ O	0.011	0.005	0.337	0.280	0.168	0.425	0.038

	Fractional Composition of Wastes						
	C-111	C-112	S-102	SX-106	TX-105	TX-118	U-107
Li ₂ O	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CaO	0.426	0.593	0.000	0.000	0.000	0.000	0.000
MgO	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fe ₂ O ₃	0.042	0.002	0.023	0.102	0.167	0.026	0.077
Al ₂ O ₃	0.256	0.097	0.582	0.388	0.595	0.240	0.650
ZrO ₂	0.007	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.256	0.302	0.058	0.197	0.060	0.250	0.228
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Cr ₂ O ₃	0.000	0.000	0.024	0.020	0.000	0.000	0.000
F	0.000	0.000	0.000	0.001	0.000	0.004	0.001
P ₂ O ₅	0.012	0.005	0.006	0.038	0.002	0.159	0.020
SO ₃	0.000	0.000	0.000	0.003	0.001	0.009	0.001
NobMet	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mass	24485	65673	36537	45273	42200	412495	11504

INDEX

- a posteriori methods, 188
- Aarts, 101, 102, 118, 211
- active, 13, 52, 55, 56, 59–61, 70, 71, 73, 74, 97, 226
- adjoint equation, 219, 224, 226, 249–253, 262, 264
- adjoint variable, 219, 224, 226, 231, 249–251
- Ahuja, 106, 117
- Arbel, 34
- Aris, 227, 265
- Arnold, 156, 174
- Arora, 72

- Bailey, 209
- basic
 - solution, 15
- batch distillation, 241, 250, 251, 266
 - equilibrium, 242, 243, 245
- Bazarra, 72
- Beale, 8, 117, 131, 172
- Beckman, 151, 174
- Beightler, 1, 8, 72
- Bellman, 219, 227, 229, 236, 265
- Benson, 208
- Bernoulli, 2, 217
- beta distribution, 147
- Betts, 265
- BFGS, 66–68, 74
- Biegler, 8, 72, 117
- binary
 - variable, 78, 85–87, 90, 93–95, 97, 98, 113, 150, 176
 - representation, 103, 124

- Birge, 8, 156, 173, 208
- blending
 - discrete, 29, 108–110
 - single, 29, 107, 109, 113
 - single blend, 29
- blending problem, 28, 69, 107–110, 164, 169, 179, 199, 200, 202–205
- Boltyanskii, 219, 265
- Boltzmann distribution, 100
- Boltzmann’s constant, 100
- Brachistochrone, 2, 217, 218
- branch-and-bound method, 79–81, 83–85, 88–90, 96, 98, 109–116
- Brandenberger, 266, 271
- Brayton cycle, 123, 159
- breadth-first, 81, 83, 84, 115, 122
- Brezinski, 173
- Brown, 209
- Brownian motion, 231–233, 237, 254–257, 260, 261, 268
- Broyden, 66
- Buchanan, 187, 208

- calculus of variations, 2, 5, 217, 219–222, 225–227, 229–231, 246, 247, 249–251, 265, 267
- Carmichael, 187, 208
- Carter, 6, 8, 34, 72
- case study
 - conductivity, 28
- Cauchy distribution, 139
- CDF, 136, 140, 150, 151
- central limit theorem, 156

- chance constrained programming, 135, 138–140, 146, 172, 173
 chance distribution, 147
 Chankong, 187, 193, 196, 208
 Charnes, 139, 173, 197
 Chaudhuri, 158, 159, 170, 173
 chi-square distribution, 139
 Chiba, 117
 Cohon, 179, 180, 186, 187, 193, 194, 209
 Collins, 100, 101, 117
 combinatorial, 98–100, 107, 108, 116, 157
 compromise programming, 189
 concave function, 44–46, 71
 Conover, 151, 174
 constrained NLP, 47, 52–56
 constraint method, 189, 194–196, 208, 212
 constraint qualification, 62
 convergence, 64, 90, 106, 143, 156, 251
 Converse, 246, 265
 convex
 function, 44–46, 52, 71, 90, 225
 hull, 90
 problem, 193, 265
 set, 44–47, 90
 Cooper, 139, 173, 197
 cutting plane method, 88, 89
 cycloid, 2, 217
- Dada, 131, 174
 Dantzig, 2, 12, 35, 131, 142, 151, 156, 173
 Dantzig–Wolfe decomposition, 142
 DAOP, 217, 218, 224
 Das, 193, 194, 209, 212
 Davidon, 66, 71, 72
 decision tree, 79
 degrees of freedom, 3, 4, 7, 9
 Dennis, 193, 194, 209, 212
 depth-first, 81–84, 113–115, 122
 descriptive sampling, 151, 153, 175
 differential algebraic optimization, 217
 discontinuous, 98, 116
 discrete
 decisions, 7, 77–79, 86, 94, 104, 107, 109, 110, 159, 164
 optimization, 7, 77, 78, 103, 107, 116, 125
 variables, 7, 77–79, 86, 94, 104, 107, 109, 110, 159, 164
 discrete blending problem, 29, 108–110
 Dissanayake, 179, 210
 dissolution rate, 70
 Diwekar, 2, 8, 28, 35, 72, 107, 108, 117, 118, 123, 135, 138, 151, 153, 155–159, 166, 170, 172–174, 194, 199, 209, 210, 231, 241, 245, 247, 250, 251, 255, 256, 260, 262, 264–266, 268, 271
 Dixit, 233, 237, 255, 266
 dual
 formulation, 36
 price, 23, 26, 62
 representation, 23, 26, 62–64, 93, 97
 simplex, 23, 26, 62
 variable, 54
 Dunn, 117
 dynamic programming, 219, 227, 229, 231, 236, 237, 246, 247, 251, 258, 262, 264, 265, 267
 discrete, 78, 79
- Edgar, 72
 Edgeworth, 131, 173
 efficient solution, 180, 185
 Eglese, 100, 101, 117
 eigenvalues, 49, 50, 58
 Emmett, 35
 Eschenauer, 179, 209
 Euler, 1, 220, 221, 247
 Euler differential equations, 220
 Euler–Lagrangian
 equation, 220, 221, 247
 formulation, 220, 222, 247
 Evans, 209
 EVPI, 131, 135, 138
 expected value of perfect information, 131, 135, 138
- Fan, 225, 266
 feasibility
 condition, 15
 feasible
 points, 27, 44, 88
 region, 4, 12–14, 17, 19, 26, 27, 34, 41, 42, 71, 77, 87, 88, 126–128, 167, 169, 184, 185, 189, 191, 195

- set, 184
- solution, 13, 15, 19, 26, 47, 55, 107, 143, 184, 185, 189, 208
- space, 165, 184
- values, 185
- Fenske equation, 245, 246
- Fenske–Underwood–Gilliland equation, 246
- Fermat, 219
- Fiacco, 26, 35
- first derivative, 47, 48, 66, 219, 221
- Fletcher, 66, 72
- Follenius, 266, 271
- fractal dimension, 159
- Fu, 194, 209
- FUG equations, 246
- Fujii, 117

- GA, 99, 103–107
 - chromosome, 104, 105
 - crossover, 104–106
 - immigration, 104–106
 - mutation, 104–106
 - population, 104–106
 - reproduction, 104, 106
 - termination criterion, 104, 106
- GA–NLP, 107, 116
- Gabasov, 72
- Galileo, 2, 217
- Gamkrelidze, 219, 265
- Gass, 190, 209
- Gauss–Jordan, 15, 17, 19
- GBD, 90, 91, 93, 94, 97, 98, 108, 116, 122
- Gelatt, 100, 102, 118
- generalized Bender’s decomposition, 90, 97
- generalized reduced gradient, 67
- generating method, 187–189, 208
- genetic algorithm, 78, 98, 99, 103, 104, 106, 116–118, 123, 124, 125
- Gephart, 200, 209
- Gerber, 209
- Giesy, 179, 210
- Gill, 72
- Gilliland, 246, 266
- Gilliland’s correlation, 246
- global maximum, 44, 51, 58, 71
- global minimum, 44, 71
- global optimum, 44, 46, 47, 58, 72, 109–112, 115, 116, 158, 164
- Glover, 88, 117
- Glynn, 156, 173
- goal programming, 189, 197–199, 208, 210–212
- Goldberg, 103, 117
- Golden, 100, 101, 117
- Goldfarb, 66
- gradient, 27, 28, 47, 52, 64, 66, 67, 71
- graphical, 12, 20, 22, 43, 84, 85, 186
- Gray, 179, 211
- GRG, 67, 68, 71
- Gross, 246, 265
- Grossmann, 8, 72, 117
- Guarnieri, 117
- Guass elimination, 13

- H–J–B equation, 227, 229, 230, 236, 237, 257
- Haimes, 187, 193, 194, 196, 208, 209
- Hamilton–Jacobi–Bellman equation, 219, 227, 229, 236
- Hamiltonian, 219, 224–226, 229, 249–253, 262, 264
- Hammersley points, 153, 155
- Hammersley sequence sampling, 151, 153, 154, 156, 159, 166, 170–172
- Hansen, 72
- hazardous, 28
- hazardous waste case study, 28, 69, 87, 107, 164, 199, 240
 - component bounds, 30–33, 69, 168, 169
 - conductivity, 31, 69–71
 - crystallinity constraints, 30, 32, 33, 69, 168, 169
 - frit, 28, 29, 31, 32, 34, 70, 71, 107–113, 115, 116, 169–172, 199–207
 - optimal solution, 34, 70, 115, 171
 - solubility constraints, 31–33, 70, 168, 169
 - viscosity, 28, 31, 69–71
 - vitrification, 28, 29, 166, 199, 200, 205, 209
- Helton, 151, 174
- Hendry, 79, 117
- Hengestebeck–Geddes, 245
- Hengestebeck–Geddes equation, 245

- Henrion, 152, 174
 here and now, 135, 138–140, 143, 172, 177
 Hessian, 47, 48, 50, 51, 53, 66, 68
 heuristics, 1, 81, 88, 100, 108, 116, 122
 HG equations, 245, 246, 260
 high-level waste, 28, 167, 209
 Higl, 134, 156, 173
 Himmelblau, 72
 Holland, 103, 117
 Hopkins, 165, 167, 173, 205, 209
 Hoza, 28, 35, 108, 165, 167, 172–174, 199, 205, 209, 210
 Hrma, 209
 HSS, 155, 156, 159, 170, 194
 Huang, 103, 117
 Hughes, 79, 117
 Hwang, 186, 187, 209

 Illman, 165, 173
 Iman, 151, 166, 174
 implicit enumeration, 81
 importance sampling, 151, 156
 indefinite, 48, 49, 58
 Infanger, 151, 173
 infeasible, 34
 solution, 17, 18
 integer programming, 7, 77, 79, 116, 117
 integer variable, 7, 78, 87, 88, 103, 159
 interior point method, 26–28, 34, 68
 interior point software, 28
 IP, 7, 9, 77–80, 84, 87–89, 94, 116, 125
 isocost, 12, 21
 isoperimetric problem, 1, 41, 42, 77, 78, 215, 216, 221, 225, 229, 237, 238
 Ito process, 232, 233, 236, 237, 254, 255, 260, 261, 264
 Ito's Lemma, 231, 235–237, 255, 260–262, 265

 Jacobian, 47, 48
 James, 151, 174
 Jantzen, 209
 Johnson, 199, 210
 Jones, 179, 211

 Kacker, 202, 210
 Kalagnanam, 151, 153, 155, 156, 166, 173, 174
 Karmarkar, 26, 28, 35

 Karpak, 211
 Karush, 53, 72
 Kershenbaum, 117
 kinematics, 215, 216, 221
 Kirk, 227, 266
 Kirkpatrick, 100, 102, 118
 KKT, 53, 55–57, 59–61, 63, 64, 66, 67, 97
 Knuth, 152, 174
 Kuhn, 210
 Kuhn–Tucker, 2, 53, 72, 179
 conditions, 53, 54, 73
 error, 55
 Karush–Kuhn–Tucker Conditions, 53, 71
 MOP, 179, 190, 208
 multipliers, 54
 Kulisch, 173
 Kumar, 179, 210

 L-shaped decomposition method, 134, 139, 142–144, 146, 151, 156, 172, 175
 Lagrange multiplier, 54, 57, 59, 61–64, 93, 220–222, 226, 231, 247–251
 Lagrangian representation, 93, 97
 Lasdon, 72, 194, 209
 Latin hypercube sampling, 151–156, 166, 170–172, 174
 least square, 4
 Leibnitz, 2
 Lettau, 118
 Levine, 118
 LHS, 151, 155, 156, 201
 Lieberman, 187, 210
 linear programming, 2, 4, 5, 7, 11, 12, 23, 26, 34, 35, 47, 174, 175, 180, 187, 208
 linearization, 90–94, 96, 142
 Lo Presti, 165, 167, 173
 local maximum, 47, 48, 51
 local minimum, 34, 44, 47, 48, 56, 71
 local optimum, 44, 71, 72, 101
 log-normal distribution, 147
 log-uniform distribution, 147
 logical constraints, 85, 86
 either-or, 87
 implication, 87
 multiple choice, 86

- Lombado, 210
 loss function, 202
 Louveau, 156, 173
 LP, 7, 9–13, 23, 25, 27, 34, 37, 42, 44,
 71, 79, 83, 87–89, 92, 107, 116,
 125, 180, 191, 197, 198
 dual, 62
 example, 14, 15, 18, 19, 33, 69–71,
 199
 formulation, 33, 41, 71
 generalized, 13
 infeasible, 18
 infinite, 21
 multiple, 21
 optimum, 12, 34, 41, 44, 71
 primal
 dual, 26, 63
 problem, 26, 28, 31
 sensitivity, 23, 62
 solution, 70
 solution method, 26, 34
 standard, 13–16, 23, 26, 62
 unbounded, 20
 Luckacs, 139, 174
 Lundgren, 200, 209

 Madansky, 135, 174
 Madhavan, 247, 250, 266
 Malik, 247, 250, 266
 Markov process, 232, 254
 master problem, 90, 93, 94, 96, 98,
 142–144
 Masud, 186, 187, 209
 mathematical programming, 78, 79, 85,
 98, 107, 108, 125, 131, 208, 210,
 211
 mathematical theory, 1, 173
 maximum principle, 219, 224–226, 229,
 231, 246–251, 258, 262–267
 McCormick, 26, 35
 MCDM, 179
 McElroy, 210
 McKay, 151, 174
 mean reverting process, 256, 257, 261
 measure of system effectiveness, 1, 7
 median Latin hypercube sampling, 153,
 154
 Mendel, 210
 Merton, 237, 258, 266

 method of steepest ascent of
 Hamiltonian, 250, 251
 Metropolis, 101, 162
 Mezei, 117
 Miettinen, 187, 189, 193, 210
 MILP, 7, 77, 84, 89, 90, 93, 94, 96, 98,
 116, 125
 Milton, 156, 174
 MINLP, 7, 77, 78, 84, 90, 93–95, 97, 98,
 107, 109, 116, 117, 121, 125, 199
 MINSOOP method, 194
 mixed integer linear programming,
 77, 89
 mixed integer nonlinear programming,
 7, 67, 77, 90, 116, 121, 150, 165
 modeling, 1, 6, 138, 146, 151, 159, 173,
 208, 211
 MOLP, 180, 183, 186, 190, 194, 197,
 198, 208
 MONLP, 180, 208
 Monte Carlo method, 148–156, 159,
 174, 175, 189
 MOP, 179, 180, 183, 186, 187, 190, 194,
 208
 Morel, 215, 241, 266
 Morgan, 152, 174
 Moré, 6, 8
 MPB, 189
 multiobjective optimization, 7, 21, 179,
 186–188, 190, 194, 202, 205, 207,
 208, 213
 multiobjective proximal bundle, 189
 multiple, 21, 22, 34, 58
 solution, 21, 22, 34
 multiple criteria decision making, 179
 multiple optima, 45, 71
 Murray, 72

 Naf, 253, 266
 Narayan, 28, 35, 72, 108, 118, 172, 174,
 199, 210
 NBI method, 194
 necessary condition, 43, 46, 47, 49,
 51–54, 56, 57, 59–61, 71, 220, 225
 negative definite, 48, 49, 51, 67
 negative semidefinite, 47, 49
 Nemhauser, 135, 174, 175
 network representation, 78–80, 122
 news vendor, 131, 132, 134, 143, 175

- news vendor problem, 131
 newsboy problem, 131
 Newton–Raphson, 64–66, 74
 Niederreiter, 174
 NISE method, 193
 NLP, 7, 9, 26, 33, 41–44, 46, 47, 51–60, 62–64, 67–71, 77, 83, 90–93, 95–98, 107, 109, 112, 115, 116, 125, 169, 170, 180, 199–202, 205, 212, 219, 251, 262–265
 no-preference method, 188, 189
 Nocedal, 8, 35, 72
 nonconvex, 202
 nondominance, 182
 non-dominated, 185, 186, 189
 point, 193
 set, 183, 185, 189, 192, 195, 196
 solutions, 185, 189, 190, 193, 194, 208
 surface, 189, 191, 193, 195, 196
 noninferior, 185, 193
 noninferior set estimation method, 193
 nonlinear programming, 2, 5, 7, 8, 26, 34, 35, 41–45, 47, 71, 72, 75, 107, 109, 169, 170, 180, 208, 210, 211, 219, 220, 231, 265
 nonnegativity, 14, 32, 33, 54, 55, 63, 70
 normal boundary intersection method, 194
 normal distribution, 139, 147, 152, 166, 232, 255
 numerical methods, 64, 71, 84, 250
 numerical optimization, 2, 5, 6, 12, 13, 35, 72

 OA, 90, 91, 93–95, 108, 109, 116, 122
 OA/ER, 94
 offline quality control, 135
 Ohkubo, 179, 210
 Okado, 117
 Olson, 179, 210
 opportunity cost, 23, 25
 optimal control, 7, 175, 180, 215, 241, 265–267
 batch, 241, 251
 batch distillation, 254, 260, 262
 definition, 218, 254
 problems, 215, 217, 219, 220, 228, 231, 241, 265
 stochastic, 219, 232, 241, 258, 260, 262, 265
 theory, 219, 220, 236, 265
 variable, 246
 Orlin, 106, 117
 Osyczka, 189, 210
 outer-approximation, 90, 95
 outer-approximation/equality relaxation, 94

 Painton, 107, 118, 123, 157, 158, 174, 210
 parameter estimation, 4
 parameter space investigation, 189
 Pareto, 183, 210
 optimal, 185, 188, 189
 set, 183, 185, 187–190, 193–195, 198, 208
 surface, 195, 196, 200, 209
 PDF, 136, 140
 penalty function, 158, 159, 162, 163, 172, 173, 203
 Petruzzi, 131, 174
 Philips, 1, 8, 72
 Pindyck, 233, 237, 255, 266
 pivot
 column, 15, 17
 element, 15, 17
 row, 15, 17
 Pontryagin, 219, 231, 246, 265, 266
 positive definite, 48–50, 53, 66
 positive semidefinite, 47, 49–51
 posterior method, 194
 potential energy, 219
 preference-based, 187–189, 197, 208
 Presti, 205, 209
 Price, 6, 8, 34, 72, 118
 primal, 26
 representation, 26, 62, 63
 principal minors, 49, 50
 principle of optimality, 219, 227, 228, 236
 probabilistic methods, 78, 98, 99, 116
 probability, 72, 100, 101, 111, 129–131, 135, 139–141, 146–149, 151, 152, 156, 159, 166, 201, 205, 210, 231, 232, 237
 problem formulation, 3
 Prékopa, 174
 PSI method, 189

- quadratic programming, 68
- quality control, 202
- quasi-Newton, 66–68, 71, 74
- Queen Dido, 1, 2, 215, 223

- Ragsdell, 8, 72
- Raiffa, 138, 175
- random, 7, 125, 138, 148–150, 152–154, 156, 159, 162, 165, 174, 253
 - cut, 105
 - elements, 135
 - jump, 101
 - move, 103
 - perturbation, 101
 - position, 105
 - search, 105
- random walk, 231, 239
- Ravindran, 8, 72, 210
- Rawest, 210
- recourse, 131, 132, 138, 142–146, 172, 173
- reduced cost, 23, 25
- Reeves, 118
- Reklaitis, 8, 72
- relaxed LP, 88
- relaxed NLP, 90
- Rico-Ramirez, 231, 241, 262, 266
- Rinooy Kan, 135, 175
- robust, 200, 202
- robust design, 193
- robustness, 193, 201, 205, 207
- Romeo, 103, 117
- Ronnooy Kan, 174
- Rosenthal, 187, 210
- Ross, 118
- Rubin, 117, 135, 173
- Russell, 125

- SA, 99–103, 107
 - cooling schedule, 101–103, 110, 111, 117
 - equilibrium, 100–103, 162
 - final temperature, 102, 111
 - freezing temperature, 101, 102, 124
 - initial temperature, 100–102, 111, 123
 - move generator, 101, 103, 110, 162
- SA-NLP, 107, 109, 115, 116, 200
- Saaty, 190, 209
- saddle point, 48, 49, 51, 58

- Saliby, 151, 153, 175
- Samuelson, 237, 258, 266
- Sangiovanni–Vincetelli, 103, 117
- Saunders, 72
- Schlaifer, 138, 175
- Schulz, 210
- Schy, 179, 210
- Sen, 134, 156, 173
- sensitivity analysis, 23, 57, 62, 174
- separation process, 240, 241
- separation sequencing, 81
- sequential quadratic programming, 67
- Sethi, 266
- shadow price, 23, 24
- Shanno, 66
- Shastri, 41
- Sherali, 72
- Shetty, 72
- shooting method, 250
- Shortencarier, 151, 166, 174
- Silverman, 179, 211
- Simon, 266, 271
- Simplex, 26, 35, 37
 - method, 2, 12, 13, 19, 21, 22, 26, 28, 34, 41, 42
 - basic solution, 15, 16, 26
 - basic variable, 13–17, 22
 - dual, 23, 26, 62
 - entering, 15–17, 19, 20, 22
 - example, 15, 18, 20, 22, 27, 35–37
 - tableau, 17, 19, 20, 22, 25
 - feasible region, 14
 - leaving, 15–17, 19, 20, 22
 - multipliers, 23, 26
 - nonbasic variable, 13, 15–17, 20, 22, 25
 - nonnegative, 13
 - ratio, 13, 15–17, 19, 20, 22, 25
 - software, 15, 28
 - solution, 22
 - tableau, 14, 15, 19, 22
- simulated annealing, 78, 98–101, 107–112, 115–118, 123, 125, 157, 158, 161, 162, 178, 211
- Singh, 179, 210
- singularities, 90, 116
- slack, 13–15, 19, 23
- Sobol, 179, 189, 211
- software, 6
 - AIMMS, 6

- AMPL, 6
- CONOPT, 6
- CPLEX, 6
- EXCEL, 6
- GAMS, 6, 33, 67, 70, 71, 75, 108, 109, 116
- HARWELL, 6
- IMSL, 6
- ISIGHT, 6
- LINGO, 6
- MATLAB, 6
- MINOS, 6, 67
- NAG, 6
- NEOS, 6
- NPSOL, 6
- OSL, 6
- SAS, 6
- SQP, 67, 68, 71
- STA, 157, 169, 170, 200, 201, 205
 - cooling schedule, 158
 - equilibrium, 162
 - move generator, 162
- stable distribution, 139
- Stadler, 186, 211
- Starkey, 179, 211
- statistical mechanics, 100
- Statnikov, 189, 211
- Steuer, 179, 187, 189, 211
- Stewart, 211
- Stirling cycle, 160
- stochastic annealing, 157–159, 161–164, 168–170, 172, 174, 178, 210
- stochastic decomposition, 134, 146, 156, 173
- stochastic dynamic programming, 231, 237, 247
- stochastic maximum principle, 231, 262, 265
- stochastic optimization, 7, 125, 136, 138, 149, 156, 157, 164, 168, 170, 172, 173
- stochastic process, 231, 232
- stochastic programming, 7, 125, 132, 135, 137, 138, 142, 156, 173–175, 208
- stopping criteria
 - GA, 106
- subproblem, 67, 90, 95, 143, 144
- successive quadratic programming, 71, 169
- sufficiency condition, 48, 49, 51, 57
- sufficient condition, 43, 47, 52, 53, 56
- Sun, 189, 211
- survival of fittest, 103
- Tabu
 - diversification, 89
 - intensification, 89
- tabu
 - list, 89
 - search, 88
- Taguchi, 135, 175, 202, 210
- Taha, 8, 35, 72, 118
- Tamiz, 179, 211
- Taniwaki, 179, 210
- Taylor series, 92, 228, 235
- Tchebycheff, 179, 210
- termination criteria
 - GA, 104, 106
 - SA, 102
 - STA, 170
- Tewari, 179, 210
- Thadathil, 208
- theory of optimization, 1, 2, 217, 219
- Thompson, 266
- Tintner, 135, 175
- Todd, 135, 174, 175
- trade-off, 161, 200, 202–205
- tree representation, 78–85, 90, 115, 122
- triangular distribution, 147
- Troutman, 266
- Tucker, 210
- Turcotte, 210
- two-point boundary value problem, 250, 251, 264
- Ulas, 241, 256, 266, 268, 271
- unbounded
 - solution, 19
- unconstrained NLP, 47, 51, 52, 56, 57, 60
- unconstrained optimum, 47, 49
- Underwood equations, 245, 246
- uniform distribution, 139, 147–153, 178
- Vajda, 135, 175
- value of research, 199, 207, 208, 210

- value of stochastic solution, 130, 134, 172, 200
- Van Slyke, 142, 175
- VanLaarhoven, 101, 102, 118, 211
- variability, 147, 165
- variance reduction technique, 151, 174
- Vecchi, 100, 102, 118
- VSS, 130, 134, 175, 200

- wait and see, 135, 138, 139, 172, 177
- Walster, 72
- Watts, 179, 211
- weighting method, 189–193, 196, 208, 212

- Westerberg, 8, 72
- Wets, 142, 175
- Whisman, 179, 211
- Wiener process, 231, 232, 254, 268
- Wilde, 1, 8, 72
- Winston, 8, 26, 35, 72, 118
- Wismer, 194, 209
- Wright, 6, 8, 28, 35, 72

- Yu, 211

- Zadeh, 190, 211
- Zeleny, 186, 189, 194, 211
- Zionts, 208, 211