

# Index

- adaptive goals 224
- advertising
  - Bass diffusion model 171–4
  - growth 201–2, 255
  - soap industry model 389, 391, 393–8, 410
- agent-based modelling 361, 362
- aging chains 317–18
- Akkermans, Henk 97, 103
- algebraic converters 80–1
- algebraic models *see* equation formulations
- alternative futures
  - fisheries 15
  - industry dynamics 258
  - rehearsing 5–6
- analogue models 413–15
- anomalous behaviour 81–4
- apparent cohesion 276–7
- archetypes 195, 281, 283–4
- Arnason, Ragnar 336, 371
- Asian boom 294–301
- asset stock adjustment 59–66
  - BBC World Service 64–6
  - cyclical dynamics 113–14, 122–3, 126, 134–8, 153–7
  - diffusion 169
  - drug-related crime 69–78, 80–1
  - dynamic complexity 21
  - equation formulations 74
  - fisheries 340
  - fractional 225–7, 268–9
  - Greenfield University simulator 61–4
  - growth 3–4, 212–13, 215–18, 225–8
  - identification 6
  - industry dynamics 268–9
  - stock and flow networks 60–1, 66–7
  - two-stage 227–8
- Atlantic Fisheries Adjustment Package 356
- automated materials handling business 51–4
- auxiliaries 125
  
- Baker Criterion 199–200, 209–10, 212, 218
- balancing loop with delay
  - cyclical dynamics 112–13, 132, 134, 142, 149
  - industry dynamics 261, 263
  - World of Showers simulator 42–3, 95–7, 102
- balancing loops 40, 43, 45–6, 50–1, 57
  - cyclical dynamics 107–8, 152
  - diffusion 163–5, 167, 171, 175, 181–2
  - fisheries 342–3, 355–6
  - growth 194–5, 248
  - industry dynamics 279–82
  - interacting 149–50
  - model validity 391–2, 409–10
  - urban dynamics 309–10
  - vertically integrated 97
- Barnard, Chester 211, 255
- Bass, Frank 166–7, 191
- Bass model of diffusion 166–74, 189
  - advertising 171–4
  - dynamics 169–70, 173–4
  - equation formulations 168–9
  - kickstarting adoption 170–1
  - simulation experiment 174
  - word-of-mouth 167–70, 173–4
- BBC World Service 64–6, 215–16
- behaviour tests 398–401, 410–11
- Behrens, William 28
- binge drinking 33
- Bio-Industrial Products (BIP) 253
- BMA *see* British Medical Association
- BMW 211–12
- board games 1–2
- Bonavista fishing community 13, 15, 17, 20, 23–4
- Booth Sweeney, Linda 27, 29
- bootstrapping 77
- boundaries 49–50, 81–4, 383–8, 411–12
  - see also* problem articulation
- bounded rationality 94, 195, 209–12, 249, 251, 264, 345
- brand switching 393–8
- British Medical Association (BMA) 327, 330
- budget-driven policies 202
- budgeting 203–4, 215–16
- bull-whip effect 97
- Bunn, Derek 361, 371
- business cycles 140–2
- Business Dynamics: Systems Thinking and Modelling for a Complex World* (Sterman) 377–9
- business growth *see* growth

## 420 ■ Index

- capacity
  - bias 276, 284, 291, 300, 302-3
  - carrying capacity 4-5, 18
  - expansion
    - business growth 197, 225-9, 240, 242, 244-8
    - industry dynamics 265, 294, 303, 305
  - industry 206
  - reduction 226
  - utilisation 221-2, 249-50
  - see also* production capacity
- capital investment *see* investment
- Carnegie School 211
- carrying capacity 4-5, 18
- causal links 39, 66-7, 69-71, 84, 253
- causal loop diagrams 26
  - algebraic models 43-4
  - basic tips 54-7
  - ceteris paribus* assumption 50-1, 52
  - congestion patterns 34-5
  - conventions 39-40, 43, 50-1, 55-6
  - cyclical dynamics 109-10, 149
  - diffusion 181
  - drug-related crime 48-9, 69
  - dynamic complexity 40, 41-3
  - dynamic hypothesis 42
  - growth 197-8
  - link polarity 39-40, 43, 50-1, 55-6
  - model validity 409-10
  - real-world processes 43-5
  - side effects 34-6
  - simulated dynamics 45-6
  - slow-to-respond showers 42-3
  - technology-based growth businesses 52-4
  - time delays 40, 42-3
  - urban dynamics 309-10
  - variables 54-5
  - visual layout 56-7
- cellular automata 362
- ceteris paribus* assumption 50-1, 52, 291
- Checkland, Peter 147-8, 151, 160
- chronic cyclicity 139-46
- Classic FM 153-5
- climate change 27, 271, 346
- climate-economy model 27
- closed-loop models 403
- Clover, Charles 7, 9, 28, 352, 371
- cohesion, apparent 276-7
- commercialisation 278, 280
- common property problem 336
- communication 155-7
- competition
  - diffusion 175, 176, 179-81, 182-6
  - feedback systems thinking 53-4
  - model validity 389-90, 393-8, 402-3, 408-10
- complex randomness 367
- conceptualisation 1-2, 6
  - cyclical dynamics 26, 111-14
  - growth 231
  - industry dynamics 262, 264
  - model validity 382, 385
  - public policy 307, 309-12
  - urban dynamics 309-12
- confidence-building tests 26, 377-413
  - behaviour tests 398-401, 410-11
  - equation formulation tests 392-405
  - family member tests 408, 411-12
  - goodness-of-fit 398-405, 411-13
  - learning tests 405-10
  - partial model tests 406-8, 411-12
  - policy implication tests 408-9, 411-12
  - structure tests 381-92, 411-12
- congestion patterns 32, 33, 34-5
- contagion model 167-70, 172
- convergence 6
- converters 66-7, 80-1, 84
  - cyclical dynamics 114-15, 125
  - diffusion 189
  - non-linear 219-20
- coordinating networks 66-7
- corrective action 208-9
- coupling formulations 101-3
- Coyle, Geoff 150, 160
- creativity 6
- crime spirals 47, 68, 78-9, 82
- cunning fish scenario 23-5
- cyclical dynamics 105-61
  - asset stock adjustment 113-14, 122-3, 126, 134-8, 153-7
  - business cycles 140-2
  - causal loop diagrams 109-10, 149
  - chronic cyclicity 139-46
  - conceptualisation 26
  - declared worldviews 151-5
  - demand surges 117-19, 130-4, 139-40
  - dynamic hypothesis 106, 107-8, 109
  - equation formulations 26, 106, 110-11, 119-23, 135-9, 157
  - fisheries 351-2, 355, 357-8
  - forecasting 114-17, 120-1, 126, 149
  - fundamental modes of dynamic behaviour 107-8
  - hard models 146-8
  - I Spy dynamics 148-9

- industry cyclicality 140–2
- information feedback networks 125–7, 140, 157
- information smoothing 120–1, 126, 138–40, 157–9
- iterative nature 106–7, 155
- model communication 155–7
- model validity 378–9, 400, 403, 415
- modelling for learning 146–55
- modelling process 105–7
- non-linearities 108
- operating constraints 129–34
- performance over time 111–19, 143–6
- policy formulation and evaluation 106, 143–6
- policy structure diagrams 155–7
- problem articulation 105–6, 108, 114–17, 128–9
- production control 111–46
- radio broadcasters 153–5
- scenarios 110–11
- sector maps 109, 110, 113–14, 134, 149
- simulations 26, 124–7, 130–4
- soft models 146–53, 154
- standard formulations 120–1, 122–3, 135–8
- stock and flow networks 108–10, 113–15, 119–23, 128–30, 134–9, 158
- structural clues 112
- team model building 108–11
- testing 106
- time delays 108
- transfer of insight 111
- what-ifs 110–11, 143–6
- workforce management 111–19, 128–46
  
- Dangerfield, Brian 187, 191, 361, 371
- databases 378, 382–3
- Davis, Ged 304
- de Geus, Arie 257, 306
- decision-making
  - growth 199–201, 203, 209–13
  - industry dynamics 264–78
  - model validity 388–92
  - stakeholders 264–78
- declared worldviews 151–5
- Delauzun, Francois 65, 85, 155, 160
- delayed feedback *see* balancing loop with delay
- delivery delays 219–24, 233–40, 242, 244–7, 255
- Dellaert, N. 97, 103
- delta-time 62
- demand
  - amplification 97
  - elasticity 84
  - industry dynamics 260–1, 288, 294–301
  - surges 117–19, 130–4, 139–40
  
- Derrick, S. 320, 372
- deterministic complexity 369
- development costs 266–8
- diagnostic simulations 110–11
- Diehl, Ernst 304, 306
- diffusion 163–91
  - advertising 171–4
  - Bass model 166–74, 189
  - causal loop diagrams 181
  - competition 175, 176, 179–81, 182–6
  - dynamics 169–70, 173–4
  - equation formulations 168–9, 188–9
  - feedback systems thinking 163–5, 167–9, 171, 175, 181–2
  - Fliers simulator 185–7, 188–90
  - forecasting 187
  - growth dynamics 163–91
  - kickstarting adoption 170–1
  - low-cost air travel 174–87
  - marketing 171, 177, 182–6
  - new product adoption 164–6, 169–71, 176–9, 187
  - S-shaped growth 163–5, 175, 187
  - scenarios 182–7
  - simulations 174, 182–7
  - stock and flow networks 164–9, 171–2, 180
  - word-of-mouth 164, 167–70, 173–4, 177–80, 184
- dimensional consistency 72–3, 383, 411
- discrete-event simulation 361, 362–70
  - feedback systems thinking 366–7
  - fisheries 363–70
  - harvested fisheries 365–70
  - stock and flow networks 364
  - tipping points 368
- diseases 187
- disequilibrium 200
- drug-related crime
  - causal loop diagrams 48–9, 50–1, 69
  - ceteris paribus* assumption 50–1
  - community sector 67–8, 76–7, 80
  - cyclical dynamics 108–9
  - drug users sector 70–1
  - dynamics 78–9, 81–4
  - equation formulations 71–6, 80–1
  - event-oriented thinking 33
  - feedback systems thinking 46–51
  - funds required formulation 73
  - modelling dynamic systems 67–84
  - police allocation formulation 75–6, 78
  - police department sector 69–70, 77–80, 82
  - price formulation 73–5, 78, 81, 83–4
  - scope/boundary of factors 49–50

## 422 ■ Index

- drug-related crime (*Cont.*)
    - sector maps 68, 77
    - simulation experiments 76–84
    - stock and flow networks 74–5
    - street market sector 70, 78–81, 82–3
  - Dudley, Richard 346, 371
  - dynamic complexity
    - cunning fish scenario 23–5
    - fisheries 21–5
    - growth 247–8
    - interdependencies 21
    - modelling dynamic systems 85
    - non-linearities 21, 23
    - reduced 23–5
    - slow-to-respond showers 87
    - time delays 40, 41–3
    - World of Showers simulator 87, 91–5, 96–7, 102
  - dynamic hypothesis 42
    - cyclical dynamics 106, 107–8, 109
    - industry dynamics 260–1
  - Dyson, Robert 5, 29
  
  - easyJet 174–87, 188–9, 211
  - elasticity of demand 84
  - The End of the Line* (Clover) 7
  - enforcement 346–9, 356
  - environmental factors
    - climate change 27, 271, 346
    - growth 3–4
    - industry dynamics 281, 284–5, 291–4, 302
  - equation formulations
    - asset stock adjustment 74, 122–3, 135–8, 180–1, 215–18, 340–1
    - fractional 225–6
    - stock depletion 135–6, 216–17
    - two-stage stock accumulation 227–8
  - Bass model of diffusion 166–9, 171–2
  - causal loop diagrams 43–4
  - confidence-building tests 392–405
  - cyclical dynamics 26, 106, 110–11, 119–23, 135–9, 157
  - diffusion 168–9, 176–80, 188–9
  - drug-related crime 71–6, 80–1
  - fisheries model 337–8, 340–3, 346–9
  - floating goal 340
  - goal formation 224
  - growth 213–28
  - industry dynamics 268–9
  - information smoothing 120–1, 137, 215–16, 221, 347
  - market growth model 215–28
  - model validity 392–405
  - modelling dynamic systems 71–6, 80–1, 85
  - morale of junior doctors 325–6
  - non-linear graphical converters 219–20, 221–2, 347–8
  - oil industry 268–9
  - production control 119–21, 122–3
  - soap industry model 392–405
  - stock and flow networks 85
  - workforce management 135–9
  - World of Showers simulator 98–101
- equilibria 200, 368
  - eroding goal archetype 281
  - European Working Time Directive (EUWTD) 314, 316, 322, 325, 327–9, 331–4
  - event-oriented thinking 32–4, 112
  - exit barriers 356–60
  - expectations 382, 406, 411–12
  - experience chains 317–18
  - expert modellers 108
  - exponential
    - averaging 121
    - growth 107–8
    - smoothing 126
  - externalities 94–5
  - extreme conditions 383, 411–12
  
  - facilitators 108
  - family member tests 408, 411–12
  - Fang, Y. 187, 191
  - fast-moving consumer goods *see* soap industry model
  - feedback loops
    - Bass model of diffusion 166–7, 171
    - competitive dynamics 409–10
    - cyclical dynamics 149–50
    - easyJet model 181–2
    - growth and underinvestment 193–4
    - market growth model 196–8
    - oil producers' model 279–84
    - road congestion 35–6
    - S-shaped growth 163–5
    - technology-based growth businesses 51–4
    - urban dynamics model 309–10
    - World of Showers simulator 95–7, 98–101
    - see also* balancing loop with delay; balancing loops; causal loop diagrams; reinforcing loops
  - feedback systems thinking 31–57
    - algebraic models 43–4
    - ceteris paribus* assumption 50–1, 52
    - cyclical dynamics 26, 112, 134, 149–50, 152, 155
    - diffusion 163–5, 167–9, 171, 175, 181–2

- discrete-event simulation 366–7
- drug-related crime 46–51
- dynamic complexity 40, 41–3
- dynamic hypothesis 42
- event-oriented thinking 32–4
- externalities 94–5
- fisheries 11, 21, 34–6, 342–3, 355–6
- growth 193–5, 196–8, 237–41
- hidden feedback 38–9
- identification 6
- industry dynamics 278–84
- interpreting business/society situations 31–4
- real-world processes 43–5
- shift of mind 37, 46
- side effects 34–6, 37
- simulated dynamics 45–6
- slow-to-respond showers 41–6
- technology-based growth businesses 51–4
- urban dynamics 309–10
- see also* balancing loop with delay; balancing loops; causal loop diagrams; reinforcing loops
- Fiddaman, Thomas 27–9, 361, 371
- fidelity 413–17
- The Fifth Discipline* (Senge) 37
- finance-driven policies 204–6
- financial services industry 141–2
- Finsgud, Lars 177, 191
- first-order smoothing 158–9
- Fish Banks, Ltd simulator (Meadows, *et al*) 8–10
- Fisher, Lawrence 308, 371
- fisheries 7–25
  - balancing catch and regeneration 337–9
  - base case 349–52
  - common property problem 336
  - conservation policies 17–18
  - cunning fish scenario 23–5
  - cyclical dynamics 351–2, 355, 357–8
  - discrete-event simulation 363–70
  - dynamic complexity 21–5
  - dynamics 7–10, 17–18
  - event-oriented thinking 33–4
  - exit barriers 356–60
  - feedback systems thinking 34–6
  - Fish Banks, Ltd simulator 8–10
  - fish density 10–12, 22–3, 352–4
  - fleet expansion 16–17, 18–20, 335–6, 337–9, 355
  - formulation of deployment policy 346–9
  - gaming simulator 13–20
  - harvested 13–25, 337–46, 365–70
  - investment 340–5
  - management 18–20, 335–6, 346, 354–6
  - maximum sustainable yield 335, 352
  - natural 10–13, 337, 363–5
  - non-linearities 21, 23
  - performance over time 18–23
  - policy design 345–60
  - public policy 307, 335–60
  - regeneration 7, 10–14, 18–20
  - regulatory policy 335–6, 345–60
  - simulated dynamics 12–13, 18–20, 343–5, 349–52
  - stock and flow networks 338, 340, 342–3, 347–9
  - surveillance and enforcement 346–9, 356
  - sustainability 9, 20, 25, 345–55, 360
  - thought experiments 15–18, 23–5
  - tipping points 336, 339, 340–5, 348
  - weakly regulated 354–6
- flexibility 315, 327–9, 333
- Fliers simulator 185–7, 188–90
- floating goals 107–8, 343
- Ford, Andrew 361, 371
- forecast-driven policies 203
- forecasting
  - cyclical dynamics 114–17, 120–1, 126, 149
  - information smoothing 120–1, 126
  - scenarios 187
- formal models 374–7
- Forrester, Jay W. 2–3, 28, 96, 103, 121, 160, 195, 201, 208, 211–12, 256, 307–14, 361–2, 371, 376–8, 382, 400–1, 417
- fractional asset stock adjustment 225–7, 268–9
- Friedman, T. 362, 371
- fundamental modes of dynamic behaviour 107–8
- gain 233, 253–5
- Gary, Shayne 253, 256
- ghosting variables 76
- Ginsberg, Ari 98, 101, 103
- GlaxoSmithKline (GSK) 95–7
- global
  - carrying capacity 4–5
  - recession 284–5
  - warming 27, 271, 346
- Go airlines 211
- goal formation 206–7, 209, 211, 224, 244–7
- goal-seeking behaviour
  - cyclical dynamics 107–8, 152
  - slow-to-respond showers 41–6, 87
- goodness-of-fit 378, 398–405, 411–13
- Google 212
- graphical converters
  - capacity expansion fraction 225–6
  - capacity utilisation 221–2
  - delivery delay 219–20

## 424 ■ Index

- graphical converters (*Cont.*)
  - diffusion 189
  - fish density 337-8, 341-2
  - modelling dynamic systems 80-1, 84
  - oil industry dynamics 266-8
  - see also* non-linearities
- green mindset 281, 284-5, 291-4, 302
- Greenfield University simulator 61-4
- greenhouse gas emissions 27, 271, 346
- growth 193-256
  - asset stock adjustment 3-4, 212-13, 215-18, 225-8
  - balancing loops 194-5, 248
  - bounded rationality 209-12
  - capacity expansion 197, 225-9, 240, 242-3, 244-8
  - causal loop diagrams 52-4, 197-8
  - cyclical dynamics 107-8
  - decision-making 199-201, 203, 209-13
  - delivery delays 219-24, 233-40, 242, 244-7, 255
  - dynamic complexity 247-8
  - equation formulations 213-28
  - feedback systems thinking 51-4, 193-5, 196-8
  - fisheries 341-2
  - formulation guidelines 198-207, 209-10
  - fundamental modes of dynamic behaviour 107-8
  - gain 233, 254
  - information feedback networks 203, 207-9
  - information filters 210, 213
  - information flows 199, 201-7, 249
  - investment 193-5, 204-6, 223-8, 237, 241-7
  - loop strength 232-3
  - management optimism 242-4, 248
  - management and policy 207-9, 210, 213
  - market growth model 195-8, 201-7
  - operating policies 201-7
  - policy design 247-8
  - policy structure diagrams 213-41, 248-52
  - production capacity 227-8, 234, 239-40, 249-50
  - recovery 238, 240-1
  - reinforcing loops 193-7, 213-14, 227, 232-3, 249, 253-5
  - sales growth 213-22, 229-37, 248
  - sector maps 196-7
  - simulation experiments 228-41
  - standard formulations 215, 216-18
  - urban dynamics 307, 308-14
  - with overshoot 107-8
  - see also* diffusion; limits to growth
- GSK *see* GlaxoSmithKline
- Haji-ioannou, Stelios 176
- handovers 321-2
- hard models 146-8
- hard OR models 373
- Hardin, Gilbert 336, 371
- Harley-Davidson 95-7, 408
- harvested fisheries 13-25, 337-46, 365-70
- health care
  - base runs 322-4, 332
  - conclusions from study 331-4
  - flexibility 315, 327-9, 333
  - handovers 321-2
  - intangibles 324-5, 327
  - junior doctors 315, 316-20, 322-7, 329-34
  - medical students 316-19
  - medical workforce planning model 316-20, 322-3, 329-34
  - model overview 326-7
  - patient care 320-2, 323-4, 332-3
  - quantitative policy changes 334
  - simulations 329-31
  - specialist doctors 316-20, 322-3, 325, 331, 333-4
  - stock and flow networks 317, 321, 326
  - work-life balance 315, 327-9, 333
  - workforce management 307, 314-34
- hidden dependencies 91-5, 98-101
- hidden feedback 38-9, 76
- high price scenario 299-301
- high-fidelity modelling 374
- Hirsch, Gary 57
- Homer, Jack 47, 57, 84, 85
- Honda 206
- housing *see* urban dynamics
- I Spy dynamics 148-9
- IBM 95-7
- if-then-else function 212, 396
- illustrative models 413-15
- incentives 211
- independent oil producers 262, 265-6, 277-8, 280, 286-99
- Industrial Dynamics* (Forrester) 2, 208
- industry
  - capacity 206
  - cyclicity 140-2
  - standards 283-4
- industry dynamics 257-306
  - Asian boom 294-30
  - capacity expansion 265, 294, 303
  - decision-making 264-78
  - demand 260-1, 288, 294-301

- development costs 266–8
- dynamic hypothesis 260–1
- environmental factors 281, 284–5, 291–4, 302
- equation formulations 268–9
- feedback systems thinking 278–84
- global recession 284–5
- high price scenario 299–301
- investment 265–6, 268–9, 290, 294–9
- microworlds 304–6
- model development process 261–4
- oil industry 257–306
- policy structure diagrams 268–9
- problem articulation 258–61
- scenarios 258, 277, 285–304
- stakeholders 264–78
- supply squeeze/glut 286–91
- unforeseen events 277–8
- information feedback networks
  - cyclical dynamics 125–7, 140, 157
  - growth 203, 207–9
- information filters
  - fisheries 345
  - growth 210, 213
- information flows 66
  - cyclical dynamics 114, 134
  - growth 199, 201–7, 249
- information smoothing
  - cyclical dynamics 120–1, 126, 138–40, 157–9
  - fisheries 347
  - growth 215–16, 221
- interacting feedback loops
  - cyclical dynamics 149–50
  - diffusion 163–5, 167, 171, 175, 181–2
  - growth 193–5, 237–41
  - World of Showers simulator 96
- interdependencies
  - causal loop diagrams 26
  - cyclical dynamics 144, 150, 151
  - dynamic complexity 21
  - World of Showers simulator 91–5, 96, 101
  - see also* causal loop diagrams
- interlocking supply chains 96–7
- internal consistency 258
- international fisheries *see* fisheries
- inventory control 115–20, 122–7, 132–3, 143–5, 157
- investment
  - fisheries 340–5
  - growth 193–5, 204–6, 223–8, 237, 241–7
  - industry dynamics 265–6, 268–9, 290, 294–9
  - limits to growth 3–5
- invisible dependencies 91–5, 98–101
- invisible feedback 38–9, 76
- isec systems 10, 28
- iThink* modelling software 10, 28
- JIT *see* just-in-time
- Johnson, E. J. 395, 417
- junior doctors 315, 316–20, 322–7, 329–34
- just-in-time (JIT) systems 141
- Kelton, W. D. 368, 371
- kickstarting adoption 170–1
- Kumar, Nirmalya 407, 417
- Kunc, Martin 380, 417
- Lane, David 148, 150, 160
- Langley, Paul 304, 306
- Larsen, Erik R. 98, 101, 103, 304, 361, 370–1
- Law, A. M. 368, 371
- law of diminishing returns 84
- learning
  - cycles 146–55
  - laboratories 111
  - tests 405–10, 411–12
- Levin, Gilbert 47, 57
- lifecycle dynamics 163
- limits to growth 3–5
  - fisheries 341–2
  - policy structure diagrams 218–22, 250
  - sales growth 218–22, 234–5
- Limits to Growth* (Meadows) 2, 5–6, 27
- link polarity 39–40, 43, 50–1, 55–6
- Lomi, Alessandro 98, 101, 103, 370, 371
- London Business School 252, 304, 314, 380
- loop strength 232–3, 253–5
- Lovelock, James 27, 28
- low-cost air travel 174–87
- low-income housing 314
- MAE *see* mean absolute error
- Makridakis, Spyros 121, 160
- management optimism 242–4, 248
- market growth model 195–8, 201–7
- market saturation 164, 167
- marketing
  - diffusion 171, 177, 182–6
  - growth 201–2, 255
  - model validity 389, 391, 393–8, 410
- Marsh, Brian 304, 306
- Mass, Nathaniel 140, 160, 412, 417
- Massachusetts Institute of Technology (MIT) 51, 212, 308
- maximum sustainable yield (MSY) 335, 352
- Meadows, D. H. 5, 28–9, 363, 371, 411, 417

## 426 ■ Index

- mean absolute error (MAE) 398
- mean square error (MSE) 398–9
- medical handovers 321–2
- medical students 316–19
- medical workforce dynamics *see* health care; workforce management
- mental databases 378, 382–3
- mental models 374–9
- metaphorical models 413–15
- Meyer, R. 395, 417
- microworlds 111, 304–6
- Miller, A. 414, 417
- Mindstorms: Children, Computers and Powerful Ideas* (Papert) 374–6
- misconceptions 406–8, 411–12
- MIT 51, 212, 308
- model communication 155–7
- model validity 26, 373–418
  - base case 401–5
  - behaviour tests 398–401, 410–11
  - boundary adequacy 383–8, 411–12
  - brand switching 393–8
  - business systems 376–7
  - causal loop diagrams 409–10
  - competition 389–90, 393–8, 402–3, 408–10
  - confidence-building tests 377–413
  - cyclical dynamics 378–9, 400, 403, 415
  - decision-making 388–92
  - equation formulation tests 392–405
  - family member tests 408, 411–12
  - fidelity 413–17
  - formal models 374–7
  - goodness-of-fit 378, 398–405, 411–13
  - learning tests 405–10, 411–12
  - mental models 374–9
  - partial model tests 406–8, 411–12
  - policy implication tests 408–9, 411–12
  - realism 374
  - sector maps 387–8
  - soap industry model 379–405
  - social systems 376–7
  - structure tests 381–92, 411–12
  - substitute products 387, 392–3
  - supermarket pricing 391–2, 397, 404–8
  - team learning 376–7
  - transitional objects 374–6
  - usefulness 413–17
- modelling dynamic systems 59–85
  - asset stock adjustment 59–67, 74, 76, 78
  - BBC World Service 64–6
  - benefits 85
  - boundaries 81–4
  - coordinating networks 66–7
  - dimensional consistency 72–3
  - drug-related crime 67–84
  - dynamics 78–9, 81–4
  - equation formulations 71–6, 80–1, 85
  - Greenfield University simulator 61–4
  - performance over time 81–4
  - side effects 82
  - stock and flow networks 60–1, 66–7, 74–5, 85
  - symbol descriptions 66–7
- modelling for learning 146–55
- modelling symbols 10, 66, 67–71
- modes of dynamic behaviour 107–8
- modulated flow 11
- Mollona, Edoardo 65, 85, 155, 160
- Monopoly* (board game) 1–2
- morale of junior doctors 325–7, 329–34
- Morecroft, John 1, 29, 52–3, 57, 96, 98, 101, 103, 146, 154, 160, 212, 253, 256, 257, 304, 306, 368, 372, 380, 417
- Moxnes, Erling 336, 372
- MSE *see* mean square error
- MSY *see* maximum sustainable yield
- multi-loops *see* interacting feedback loops
- multipliers 311–12
  
- Naill, Roger 361, 372
- National Health Service (NHS) 314–16, 319, 324, 334
- natural fisheries 10–13, 337, 363–5
- natural resources
  - fisheries 7–25
  - limits to growth 3–5
- new product adoption 164–6, 169–71, 176–9, 187
- NHS *see* National Health Service
- Nichols, J. 29
- non-linearities
  - cyclical dynamics 108
  - fisheries 21, 23, 342–3, 355–6
  - graphical converters 219–20
- numerical databases 378, 383
  
- O'Brien, Frances 5, 29
- Occam's Razor 190
- oil industry 257–306
  - Asian boom 294–301
  - decision-making 264–78
  - demand 260–1, 288, 294–301
  - development costs 266–8
  - equation formulations 268–9
  - feedback systems thinking 278–84
  - global recession 284–5

- high price scenario 299–301
- independents 262, 265–6, 277–8, 280, 286–99
- investment 265–6, 268–9, 290, 294–9
- microworlds 304–6
- model development process 261–4
- oil price 258–61, 270–1, 293, 300, 303
- opportunists 262, 275–7, 283–7, 291, 294, 297–9, 302–3
- overview 262–3
- policy structure diagrams 268–9
- problem articulation 258–61
- quota bias 302
- quota busting 291–4
- quota setting 262–3, 272, 274–5, 281–4, 286–91
- Russia 277–8, 280, 294–9, 303–4
- scenarios 258, 277, 285–304
- stakeholders 264–78
- supply squeeze/glut 286–91
- swing producers 262, 272–4, 282, 287–8, 290–2, 297–9
- Oil World simulator 285–304
- OPEC *see* Organisation of Petroleum Exporting Countries
- open-loop steady-state gain 233, 254
- operating constraints 129–34
- operating policies 201–7, 250–2
  - budgeting 203–4, 215–16
  - customer ordering 201–2, 218, 240–1, 243
  - goal formation 206–7, 209, 211, 224, 244–7
  - investment 204–6
  - sales force expansion 202–3
- operations-driven policies 204–6, 207
- opportunist oil producers 262, 275–7, 283–7, 291, 294, 297–9, 302–3
- optimality 200
- optimism
  - growth 242–4, 248
  - industry dynamics 266, 294, 303
- order fulfilment 216–18, 221–2
- Organisation of Petroleum Exporting Countries (OPEC) 260, 262–3, 272–6, 280–91, 298, 300–3
- organisational stress 322
- oscillation 107–8, 112
- Otto, Peter 34, 57
- overproduction 258
- overshoot and collapse 107–8
  
- Papert, Seymour 374–5, 376, 417
- parameter verification 383, 411
- partial model tests 406–8, 411–12
- patient care 320–2, 323–4, 332–3
  
- Pennsylvania Oil Regions 258–60
- People Express 189–90, 251–2
- performance over time 18–23, 81–4, 111–19, 143–6
- performance targets 389
- pet theories 406–8, 411–12
- Pidd, Mike 147, 160, 362, 372–3, 375, 377, 417
- planning-driven policies 204–6
- point-by-point differences 398, 400, 414–15
- policy
  - design 247–8, 345–60
  - formulation and evaluation 106, 143–6
  - implication tests 408–9, 411–12
  - levers 92–4
  - policy makers 108
  - see also* public policy
- policy structure diagrams 155–7
  - growth 213–41, 248–52
  - industry dynamics 268–9
  - investment 223–8
  - limits to growth 218–22, 250
- pooled capacities 96–7, 98
- population growth 3–5
- Poulter, John 151, 160
- poverty 313–14
- price equalisation 184
- price sensitivity 271
- The Prize: The Epic Quest for Oil Money and Power* (Yergin) 258
- problem articulation
  - cyclical dynamics 105–6, 108, 114–17, 128–9
  - industry dynamics 258–61
  - production control 114–17
  - workforce management 128–9
- product launches 33
- production capacity
  - growth 227–8, 234, 239–40, 249–50
  - model validity 389
- production control
  - asset stock adjustment 122–3, 126, 134
  - business cycles 140–2
  - chronic cyclicity 139–46
  - cyclical dynamics 111–46
  - demand surges 117–19, 130–4, 139–40
  - desired production 119, 123, 128, 132, 150
  - equation formulations 119–21, 122–3
  - forecasting 114–17, 120–1, 126, 149
  - industry cyclicity 140–2
  - information smoothing 120–1, 126
  - inventory control 115–20, 122–7, 132–3, 143–5, 157
  - operating constraints 129–34
  - policy formulation and evaluation 143–6

## 428 ■ Index

- production control (*Cont.*)
  - problem articulation 114–17
  - simulations 124–7, 130–4
  - standard formulations 120–1, 122–3
  - stock and flow networks 119, 121–3, 128–30, 134–5, 156
  - workforce management 128–34, 139–46
- productivity
  - fisheries 352–4, 355–6
  - growth 203, 255
  - workforce management 128–9, 138–9
- profitability
  - industry dynamics 269, 289–90, 293, 296
  - model validity 381
- promotions 389, 393–8, 410
- public policy 307–72
  - agent-based modelling 361, 362
  - alternative simulation approaches 361–70
  - discrete-event simulation 361, 362–70
  - fisheries 307, 335–60, 363–70
  - health care 307, 314–34
  - urban dynamics 307–14, 362
  - workforce management 307, 314–34
- punitive production 272–3, 281–2, 287–8, 290–2, 297
- qualitative tests of fit 400–1
- quota
  - bias 302
  - busting 291–4
  - setting 262–3, 272, 274–5, 281–4, 286–91
- radio broadcasters 153–5
- Randers, Jorgen 4, 28, 29
- random processes 139–42, 367
- Ratnarajah, Mark 314, 315, 372
- realism 374, 414, 416
- recession 284–5
- recovery 238, 240–1
- recruitment 61–4
- regeneration 7, 10–14
- regulatory policy 335–6, 345–60
- reinforcing loops 40, 43, 47–9, 50–1, 57
  - cyclical dynamics 107–8
  - diffusion 163–5, 167, 171, 175, 177, 181–2
  - drug-related crime 67–8
  - fisheries 342–3, 355–6
  - gain 233, 253–5
  - growth 193–8, 213–14, 227, 232–3, 249, 253–5
  - industry dynamics 280–4
  - model validity 391–2, 409–10
  - modelling dynamic systems 76, 82
  - urban dynamics 309–10
- relative price 201–2
- Repenning, Nelson 339, 372
- reputation
  - diffusion 179, 182
  - feedback systems thinking 53–4, 56
- The Revenge of Gaia* (Lovelock) 27
- revenue allocation 215
- rewards 211
- road congestion *see* congestion patterns
- Roberts, Carole 361, 371
- Roberts, Edward 57
- Robertson, Duncan 362, 372
- Robinson, Stewart 362, 363, 368, 372
- robustness 201
- Rockerfeller, John D. 259
- Roughgarden, J. 352, 372
- Royal Dutch/Shell 257–9, 265, 304, 306
- Rubik's cube 166
- Rudolph, J. W. 339, 372
- Russia 277–8, 280, 294–9, 303–4
- Ryanair 211
- S-shaped growth
  - cyclical dynamics 107–8
  - diffusion 163–5, 175, 187
  - discrete-event simulation 365
  - dynamic hypothesis 107–8
- sanctions 346–9, 356
- Saudi Arabia 272–4, 282
- scatter lists 279, 284
- scenarios
  - cyclical dynamics 110–11
  - diffusion 182–7
  - industry dynamics 258, 277, 285–304
  - team model building 110–11
- Schelling, Thomas C. 94, 103
- Scholes, Jim 153, 160
- scope 49–50
- sector maps
  - cyclical dynamics 109, 110, 113–14, 134, 149
  - drug-related crime 68, 77
  - health care 326–7
  - market growth 196–7
  - model validity 387–8
  - oil industry model 262–4
  - soap industry model 387–8
  - team model building 109, 110
- seeing the forest and the trees 44
- self-restraint 360

- Senge, Peter 37, 44, 57, 150, 160, 193, 256, 281, 283, 306, 377, 417
- sensitivity analysis 334
- Seven Sisters oil companies 259–60
- Shanon, Diana 29, 371
- shared capacities 96–7, 98
- shared vocabularies 85
- Shell 257–9, 265, 304, 306
- Sherwood, Dennis 44, 57, 150, 160
- shift of mind 37, 46
- side effects 34–6, 37
- SimCity 362
- Simon, Herbert A. 211, 256, 416, 418
- simulation analysis 26
- single-stock smoothing 158–9
- slow-to-respond showers 41–6  
*see also* World of Showers simulator
- Smith, F. 352, 372
- smoothing *see* information smoothing
- soap industry model 379–410  
 base case 401–5  
 behaviour tests 398–401, 410–11  
 boundary adequacy 383–8, 411–12  
 brand switching 393–8  
 competition 389–90, 393–8, 402–3, 408–10  
 complete model 387–8  
 decision-making 388–92  
 equation formulation tests 392–405  
 family member tests 408, 411–12  
 goodness-of-fit 398–405, 411–13  
 industry overview 380–1  
 learning tests 405–10, 411–12  
 partial model tests 406–8, 411–12  
 policy implication tests 408–9, 411–12  
 refined model 385–7  
 sector maps 387–8  
 simple model 383–5  
 structure tests 381–92, 411–12  
 substitute products 387, 392–3  
 supermarket pricing 391–2, 397, 404–8
- social  
 contagion model 167–70, 172  
 modelling 146–8, 376–7
- soft models 146–53, 154
- soft OR models 373
- Soft Systems Methodology (SSM) 151–3
- specialist doctors 316–20, 322–3, 325, 331, 333–4
- SSM *see* Soft Systems Methodology
- Standard Oil 259
- start-ups 253
- static goals 224, 244–7
- statistical fit 398–400, 411–13
- steady-state open-loop gain 233, 254
- Steenkamp, Jan-Benedict 407, 417
- Sterman, John D. 27, 29, 56–7, 62, 85, 94, 106–7, 121, 142, 146–7, 160, 167, 190–1, 199, 212, 256, 377, 379, 398, 401
- stochastic dynamics 367, 369
- stock and flow networks 60–1  
 algebraic models 85  
 coordinating networks 66–7  
 cyclical dynamics 108–10, 113–15, 119–23, 128–30, 134–9, 158  
 diffusion 164–9, 171–2, 180  
 discrete-event simulation 364  
 drug-related crime 74–5  
 fisheries 338, 340, 342–3, 347–9  
 health care 317, 321, 326  
 information smoothing 158  
 model validity 384, 386, 393–4  
 symbols used 66–7  
 urban dynamics 309–12  
*see also* policy structure diagrams
- stone circle analogy 38–9
- Struben, Jeroen 34, 57, 187, 191
- structural clues 112
- structure tests 381–92, 411–12
- structure verification 383–5, 411–12
- substitute products 387, 392–3
- success-to-the-successful archetype 283–4
- Sull, Don 175, 191
- supermarket pricing 391–2, 397, 404–8
- Supporting Strategy* (O'Brien and Dyson) 5, 177, 384, 386
- surprise behaviour 406, 411–12
- surveillance 346–9, 356
- sustainable fisheries 9, 20, 25, 345–55, 360
- swing producers 262, 272–4, 282, 287–8, 290–2, 297–9
- Systems Modelling* (Pidd) 373, 375, 377
- Tamagochi 166
- team learning 376–7
- team model building 108–11
- technology-based growth 51–4
- Theil, H. 399, 417
- Theil's Inequality Statistics 399
- time delays  
 cyclical dynamics 108  
 dynamic complexity 40, 41–3  
 World of Showers simulator 88–95  
*see also* balancing loop with delay

## 430 ■ Index

- time slicing 124
- tipping points
  - discrete-event simulation 368
  - public policy 336, 339, 340-5, 348
- traffic density *see* congestion patterns
- transfer of insight 111
- transitional objects 374-6
- two-stage asset stock adjustment 227-8
  
- underinvestment 193, 195, 251-2
- unintended dynamics 47
- urban dynamics 307-14
  - agent-based modelling 362
  - causal loop diagrams 309-10
  - conceptualisation 309-12
  - growth and stagnation in cities 307, 308-14
  - multipliers 311-12
  - policy implications 313-14
  - SimCity 362
  - stock and flow networks 309-12
- Urban Dynamics* (Forrester) 28, 307-14
- usefulness 413-17
  
- validity *see* model validity
- van der Heijden, Kees 257, 258, 306
- Venezuela 275-7
- Vennix, Jac 108, 161
- vertically integrated balancing loops 97
- visual fit 400-1, 411-13
  
- Warren, Kim 60, 62, 85
- welfare spending 313-14
- what-ifs
  - cyclical dynamics 110-11, 143-6
  - diffusion 182
  - industry dynamics 258
- Whitestone, Deborah 190, 191
- Winch, Graham 320, 372
- Wolstenholme, Eric 150, 161, 361, 372
- word-of-mouth
  - business growth 201-2
  - diffusion 164, 167-70, 173-4, 177-80, 184
- work-life balance 315, 327-9, 333
- workforce management
  - asset stock adjustment 134, 135-8
  - business cycles 140-2
  - chronic cyclicity 139-46
  - cyclical dynamics 111-19, 128-46
  - demand surges 130-4, 139-40
  - equation formulations 135-9
  - flexibility 315, 327-9, 333
  - growth 202-3, 215-16, 236, 240-1
  - health care 307, 314-34
  - industry cyclicity 140-2
  - information smoothing 138-40
  - morale 325-7, 329-34
  - operating constraints 129-34
  - planning 138-9
  - policy formulation and evaluation 143-6
  - problem articulation 128-9
  - production control 128-34, 139-46
  - productivity 128-9, 138-9
  - simulations 130-4
  - standard formulations 135-8
  - stock depletion 135-6
  - stock and flow networks 130, 134-9, 156
- Working Time Directive (EUWTD) 314, 316, 325, 327-9, 331-4
- World Dynamics* (Forrester) 2-4, 5-6, 27-8
- World Dynamics model 400-1
- World Service 64-6, 215-16
- World of Showers simulator 26, 87-103
  - balancing loop with delay 95, 102
  - coupling formulations 101-3
  - dynamic complexity 87, 91-5, 96-7, 102
  - equation formulations 98-101
  - externalities 94-5
  - five-star hotel 88-91, 95
  - GlaxoSmithKline, IBM and Harley-Davidson 95-7
  - hidden shower-taker 91-5, 98-101
  - interacting balancing loops 96
  - interdependencies 91-5, 96, 101
  - model validity 415-16
  - policy levers 92-4
  - redesigning 92-7
  - simulations 101-3
  - two-star hotel 91-4, 95, 98-103
- worldviews, declared 151-5
- Worm, B. 335, 372
- written databases 378, 383
  
- Yergin, Daniel 258, 306
  
- Zahn, Erich 28, 29