

Index

- AA. *See* Arithmetic averaging (AA)
- ABM. *See* Agent-based modelling (ABM)
- Adaptive neuro-fuzzy inference system (ANFIS), 63, 391, 394–395, 399–400
- forecast accuracy of developed models, 401–402
 - input selection and prediction modelling, 396–397
 - limitations, directions for future studies and potential applications, 404–405
 - practical implications, 403–404
 - R-Code for ANFIS, 410–411
 - tender price index forecasting, 402–403
 - univariate modelling techniques, 391–394
 - univariate models application, 398
- Advanced modelling techniques, 416, 419
- AEC company. *See* Architect-engineer-construction Company (AEC company)
- Age hierarchy, 377
- Agenarisk software package, 306
- Agent unified modelling language (AUML), 164, 165
- Agent-based model, 163–164
- Agent-based modelling (ABM), 83–84, 154–155
- Agglomerative hierarchical clustering, 67
- Aggregated score, 343
- Aggregation, 232, 242–243
- See also* Fuzzy aggregation
- Agreement. *See* Idempotence
- AHP. *See* Analytic hierarchy process (AHP)
- AI models. *See* Artificial intelligence models (AI models)
- AIC. *See* Akaike information criteria (AIC)
- Akaike information criteria (AIC), 399
- Algebraic product t -norm, 124–131
- α -cut method, 19–20, 160
- Analytic hierarchy process (AHP), 21–22, 70, 185–186, 189, 235, 280, 285, 306
- fuzzy extensions, 280–288
- Analytic network process (ANP), 83, 185–186, 190
- ANFIS. *See* Adaptive neuro-fuzzy inference system (ANFIS)
- ANN. *See* Artificial neural network (ANN)
- ANP. *See* Analytic network process (ANP)
- Ant colony system, 42, 92
- Appraisal, 313
- AR model. *See* Autoregression model (AR model)
- Archimedean t -norms, 117–118
- Architect-engineer-construction company (AEC company), 415
- project execution process for, 416
- Area methods, 286–287
- Arithmetic averaging (AA), 242–243
- Arm gestures, robotic manipulator modelling of, 453–460
- Artificial bee colony algorithm, 42
- Artificial intelligence models (AI models), 64, 392, 393, 402, 404–405

- Artificial neural network (ANN), 52, 157
 hybridisation of fuzzy logic with, 52, 63–66
- Associativity property, 245
- @Risk software package, 306, 311
- Attitude towards risk. *See* Index of optimism
- AUML. *See* Agent unified modelling language (AUML)
- Autoregression model (AR model), 393
- Average tolerance value, 327
- Backward stage process, 395
- Bell-shaped (Gaussian) membership function, 10
- BI. *See* Business intelligence (BI)
- BIM. *See* Building information modelling (BIM)
- Black box models, 405
- BOT projects. *See* Build, operate and transfer projects (BOT projects)
- Bounded difference *t*-norm, 131–136
- Box–Jenkins model, 391, 393, 398–399
- Build, operate and transfer projects (BOT projects), 90, 161
- Building design applications, 264
- Building information modelling (BIM), 366, 415
- Business intelligence (BI), 358
- C-IOWA. *See* Consistency IOWA (C-IOWA)
- Capital expenditure (CAPEX), 305
- CAPEX. *See* Capital expenditure (CAPEX)
- Cash flow analysis of resultant revenue, 311
- Causal loop diagrams (CLDs), 152–153
- Causal models, 421
- Cause-and-effect analysis
 complex, 434–436
 compound, 433–434
 simple, 424–432
- Cause-effect approach, 415
- Centre of area method (COA method), 162, 268
- Centre of gravity (COG), 16
- CFPRs. *See* Consistent fuzzy preference relations (CFPRs)
- CFs. *See* Contribution factors (CFs)
- Chaotic-based DE technique, 68
- Characteristic of fuzzy set
 alpha-cut (α -cut), 11–13, 19
 complement, 14, 18
 core, 11
 height, 11
 support, 11
- CI. *See* Consistency index (CI)
- CID. *See* Concept identifier (CID)
- CL. *See* Complexity level (CL)
- Classical set, 7
See also Crisp set
- Classical set theory, 8–9
- CLDs. *See* Causal loop diagrams (CLDs)
- Closeness coefficient (CC). *See* Relative closeness index
- CLP. *See* Construction labour productivity (CLP)
- Clustering
 agglomerative hierarchical clustering, 66
 methods based on, 23–24
 model-based clustering, 67
 partitional k-means clustering, 67
See also Fuzzy clustering
- CM. *See* Construction management (CM)
- CM–FCM. *See* Construction management FCM modelling (CM–FCM)
- COA method. *See* Centre of area method (COA method)
- Coefficient of determination (R^2), 64, 69
- Coefficient of variation (COV), 317
- COG. *See* Centre of gravity (COG)
- Cognitive maps, 419
See also Fuzzy cognitive map (FCM)

- Commutativity property, 244
- Complex cause-and-effect example, 434–436
- Complexity level (CL), 293, 295, 296
- Compound cause-and-effect analysis, 433–434, 437
- Computational discrete methods, 119
- Computational methods, 119
 - extended fuzzy arithmetic
 - using algebraic product t -norm, 124–131
 - using bounded difference t -norm, 131–136
 - using drastic product t -norm, 137–141
 - for implementation
 - of extended fuzzy arithmetic, 123–124
 - of standard fuzzy arithmetic, 121–123
 - triangular fuzzy numbers, 120
- Concept identifier (CID), 434
- Concordance index, 191
- Consecutive fuzzy arithmetic operations, 116
- Consensus, 231–232, 233, 234–235, 236–237, 239, 241, 242, 270, 344
 - See also* Fuzzy consensus
- Consensus index, 264
- Consensus measures, 236
- Consensus-reaching process, 234
- Consistency index (CI), 284
- Consistency IOWA (C-IOWA), 249
- Consistency of fuzzy pairwise comparisons, 284–285
 - check for, 290
- Consistency ratio (CR), 198–199, 284
- Consistent fuzzy preference relations (CFPRs), 266
- Constrained fuzzy arithmetic, 286, 287
- Construction, 5, 9, 20, 24, 30, 39, 50, 63, 64, 80, 89, 95, 141, 150–151, 155, 171, 187, 283
 - bidding applications, 268–269
 - construction risk analysis, fuzzy hybrid techniques in, 308
 - cost, 390
 - engineering, 358, 423
 - CM–FCM model, 423–424
 - complex cause-and-effect example, 434–436
 - compound cause-and-effect analysis, 433–434, 437
 - simple cause-and-effect analysis, 424–432
 - FSD model of quality management practice, 168–170
 - fuzzy AHP application in
 - construction project
 - complexity evaluation, 288
 - consistency of fuzzy pairwise comparisons, 290
 - fuzzy pairwise comparison matrices, 289–290
 - hierarchical structure of project complexity, 288–289
 - local and global weights of criteria and sub-criteria, 290–293
 - project complexity and performance, 293–295
 - fuzzy arithmetic operations in
 - construction applications, 141–145
 - fuzzy consensus reaching and aggregation in construction industry applications, 263–270
 - fuzzy simulation technique, 168–171
 - applications of fuzzy system dynamics (FSD), 168–170
 - for construction modelling, 167–168
 - fuzzy agent-based modelling (ABM) applications, 170–171, 172
 - managers, 414
 - procurement, 266–267
 - productivity applications, 269–270
 - sector, 5

- simulation techniques, 150, 151–155
- type, 371–372
- Construction labour productivity (CLP), 67
- Construction management (CM), 414–417
 - enhancing CM tools and practices with FCM, 417–419
- Construction management FCM
 - modelling (CM–FCM), 416, 419, 423–424, 432, 438–446
- Construction projects, 185
 - essential tasks in construction project management, 364
 - cost management, 364–365
 - planning analysis, 366–367
 - safety analysis, 365–366
 - life cycle, 358
 - planning, 366
- Construction supply chain (CSC), 42
 - optimization, 48
- Context awareness, 368
- Contract-related risks, 418
- Contribution factors (CFs), 265
- Convex fuzzy set, 12–13
- Cooperative neuro-fuzzy system, 65–66
- CoSMo, 268–269
- Cost, 390
 - cost/tender price index, 390
 - estimation, 364
 - management, 364–365
- COV. *See* Coefficient of variation (COV)
- CR. *See* Consistency ratio (CR)
- Crane guidance
 - motion sensing, 460
 - signals, 452–453
- Crane guidance gesture recognition, 453
 - experimental results, 466
 - fuzzy rule for stop, 470, 471
 - hoist, 467
 - human motions, 452–453
 - lower, 468
 - motion capture with Kinect camera and Myo Armband sensors, 463–465
 - robotic manipulator modelling of arm gestures, 453–460
- Sugeno-type fuzzy inference system, 460–463
- swing, 469
- travel, 470
- Crisp hierarchy, 363
- Crisp set, 11–13, 14, 18
 - See also* Classical set
- Crystalball, 306
- CSC. *See* Construction supply chain (CSC)
- ‘Cube’ of project complexity, 288–289
- Data management strategy, 358
- Data warehouse (DW), 359–360
- Data-driven methods, 20, 22
- Datacube, 370
- DB project delivery. *See* Design build project delivery (DB project delivery)
- DE. *See* Differential evolution (DE)
- Decision criteria, 341
- Decision makers (DMs), 339
- Decision support system, 45, 358, 419
- Decision-making, 421
 - in construction management
 - applications of IF-MCDM, 221
 - FMCDM methods and applications, 197–220
 - fuzzy set theory and typical extensions, 192–197
 - MCDM process and methods, 186–192
 - processes, 5, 9, 265, 343, 367, 379
 - for project planning, 367
- Defuzzification, 16, 285–288
 - centre of area (COA), 162, 198, 268, 286
 - centre of gravity (COG), 16
 - interface, 27
 - largest of maxima (LOM), 162
 - mean of maxima, 17
 - median of area, 16
 - method, 206, 350

- middle of maxima, 162, 286
- smallest of maxima, 162
- Defuzzified trapezoidal type-2 FS
 - approach (DTraT approach), 216
- Degree of belonging, 307
- Degree of experts, 234–235
- Degree of membership. *See* Membership functions
- Degree of truth. *See* Membership functions
- Degrees of freedom (DOF), 210, 454
- Degrees of support (DoS), 26
- Delphi method, 339, 344
- Denavit–Hartenberg model (D–H model), 453, 454
- DES. *See* Discrete event simulation (DES)
- Design build project delivery (DB project delivery), 267
- Deterministic solutions, 314
- Deterministic values, 88–89, 155
- Deterministic variable, 156, 157, 162
- D–H model. *See* Denavit–Hartenberg model (D–H model)
- Dice operation, 361
- Differential evolution (DE), 43
- Dimensions, 363, 368, 369
- Direct assignment of membership functions, 20–21
- Discordance index, 191
- Discrete event simulation (DES), 83–84, 152
- Distance measure, 27, 212, 261, 265, 269
- Distribution methods, 286–287
- DMs. *See* Decision makers (DMs)
- DOF. *See* Degrees of freedom (DOF)
- DoS. *See* Degrees of support (DoS)
- .NET framework, 464
- Drastic product t -norm, 137–141
- Drill-down operations, 361
- Drilling cost, 325
- Dry-hole risk, 311
 - for subsea option, 314–315
- DTraT approach. *See* Defuzzified trapezoidal type-2 FS approach (DTraT approach)
- DW. *See* Data warehouse (DW)
- Dynamic modelling of arm gestures, 453–454
- Dynamic systems, 152–153
- Earthmoving operation, 142
- Earthmoving process-type system, 152
- EAs. *See* Evolutionary algorithms (EAs)
- EBS financial system. *See* Enterprise business suite financial system (EBS financial system)
- Econometric techniques, 392
- Economic criteria, 79
- Economic growth, 5
- Economic markets, 414
- Economic screening, 313
 - concept selection parameters, 321
 - dry-hole risk for subsea option, 314–315
 - fuzzy AHP technique, 318–323
 - MCS, 314
 - normalised weight distribution, 322
 - pairwise comparison of factors, 322
 - production risk for subsea option, 315–318
 - tolerance value for membership functions of fuzzy sets, 323
- Effective risk analysis, 305
- Effective risk management, 304–305
- EFNIM. *See* Evolutionary fuzzy neural inference model (EFNIM)
- EKF. *See* Extended Kalman filter (EKF)
- ELECTRE. *See* Elimination and choice expressing reality (ELECTRE)
- Elimination and choice expressing reality (ELECTRE), 70, 186, 191
- Empirical data, 337, 339, 343
- Empirical evidence, 396

- Enterprise business suite financial system (EBS financial system), 421
- Enterprise project planning system, 422
- Enterprise resource planning system (ERP system), 421
- Entropy for fuzzy sets, 3
- Entropy-based fuzzy AHP, 287, 290, 293, 296
- Environmental criteria, 78–79
- ERD well solution. *See* Extended reach drilling well solution (ERD well solution)
- ERP system. *See* Enterprise resource planning system (ERP system)
- ETL process. *See* Extract, transform and load process (ETL process)
- Euler angle, 452
- Evolutionary algorithms (EAs), 42
- Evolutionary fuzzy neural inference model (EFNIM), 52, 64–65
- Expert judgement, 21, 30, 162–163, 185–187, 231, 267, 284, 290
- Expert knowledge, 6–7, 63, 70, 80, 84, 88–90, 150, 158, 162, 364, 368
- Expert systems, 417
 - See also* fuzzy expert system
- Expertise, 417
- Extended fuzzy arithmetic, 113, 116–119
 - using algebraic product t -norm, 124–131
 - using bounded difference t -norm, 131–136
 - using drastic product t -norm, 137–141
 - implementation, 123–124
- Extended Kalman filter (EKF), 456–458
- Extended reach drilling well solution (ERD well solution), 312
- Extension principle, 116
- Extract, transform and load process (ETL process), 359
- F-PROMETHEE. *See* FS-based preference ranking organisation method enrichment evaluation (F-PROMETHEE)
- FABM. *See* Fuzzy agent-based modelling (FABM)
- FAHP. *See* Fuzzy analytic hierarchy process (FAHP)
- Failed risk management, 304–305
- FATLBO. *See* Fuzzy adaptive teaching-learning-based optimization (FATLBO)
- FCM. *See* Fuzzy c-means (FCM); Fuzzy cognitive map (FCM)
- FCM-PSO. *See* Fuzzy c-means-particle swarm optimisation (FCM-PSO)
- FCQRA framework. *See* Fuzzy consensus qualitative risk analysis framework (FCQRA framework)
- FDES. *See* Fuzzy discrete event simulation (FDES)
- FDMM. *See* Fuzzy distance measurement method (FDMM)
- Feedback, 420
 - loops, 153
 - processes, 153–154
- FEGA-PSO. *See* Fuzzy enabled GA-PSO method (FEGA-PSO)
- FES. *See* Fuzzy expert system (FES)
- FIS. *See* Fuzzy inference system (FIS)
- FL. *See* Fuzzy logic (FL)
- Flat fuzzy numbers, 19
- Flexible management of essential construction tasks
 - essential tasks in construction project management, 364–367
 - example of queries resolution, 379–382
 - fuzzy multi-dimensional model, 362–364

- fuzzy multi-dimensional structure, 367–379
- information, 358–359
- measure and dimensions, 383
- multi-dimensional structure, 359–362
- FLINMAP. *See* Fuzzy linear programming technique for multi-dimensional analysis of preference (FLINMAP)
- FMCDM. *See* Fuzzy multi-criteria decision-making (FMCDM)
- FMCS. *See* Fuzzy Monte Carlo simulation (FMCS)
- FN-IOWA. *See* Fuzzy number induced ordered weighted averaging (FN-IOWA)
- FNIS. *See* Fuzzy negative ideal solution (FNIS)
- FNNs. *See* Fuzzy neural networks (FNNs)
- FOAM. *See* Fuzzy optimal aggregation method (FOAM)
- Footprint of uncertainty (FOU), 196
- Forecast accuracy of developed models, 401–402
- Forward recursive equations, 454
- FOU. *See* Footprint of uncertainty (FOU)
- FPIS. *See* Fuzzy positive ideal solution (FPIS)
- FPRC approach. *See* Fuzzy preference relation consensus approach (FPRC approach)
- FPWA operator. *See* Fuzzy prioritised weighted averaging operator (FPWA operator)
- FRBS. *See* Fuzzy rule-based system (FRBS)
- Frequency response function (FRF), 67–68
- FRF. *See* Frequency response function (FRF)
- FSAM. *See* Fuzzy similarity aggregation method (FSAM)
- FSC model. *See* Fuzzy similarity consensus model (FSC model)
- FSD. *See* Fuzzy system dynamics (FSD)
- FSE. *See* Fuzzy synthetic evaluation (FSE)
- FST. *See* Fuzzy set theory (FST)
- Fuzzification, 16–17, 394
- Fuzziness accumulation, 116
- Fuzzy ABM model of construction crew motivation and performance, 170
- Fuzzy adaptive teaching-learning-based optimization (FATLBO), 42–43
- Fuzzy agent-based modelling (FABM), 84, 91–92, 162–167
 - applications, 170–171, 172
- Fuzzy aggregation, 112–113, 242
 - classification of fuzzy aggregation operators and properties, 243–245
- FN-IOWA, 248–251
 - fuzzy aggregation operators for MCGDM problems, 245
 - fuzzy prioritised weighted aggregation operators, 251–257
 - fuzzy prioritized weighted averaging operator (FPWA operator), 252
 - fuzzy TOPSIS-based approach for prioritised aggregation, 257–263
- FWA, 245–246
- LOWA, 246–248
- Fuzzy analytic hierarchy process (FAHP), 70–79, 235, 270, 280, 318–323
 - application
 - in evaluating construction project complexity, 288–295
 - in oil drilling, 310–313
 - computation in subsea drilling option, 324–331

- investment appraisal for oil drilling
 - methods, 304, 323
 - appraisal, 313
 - economic screening, 313–323
 - risk analysis in projects, 305–310
- Fuzzy arithmetic, 19
 - alpha-cut (α -cut) approach, 19–20
 - extension principle approach, 19–20
- Fuzzy arithmetic operations, 238–239
 - computational methods, 119–141
 - in construction applications, 141–145
 - exact mathematical methods, 112–119
 - fuzzy addition, 113, 238
 - fuzzy division, 113, 120
 - fuzzy multiplication, 113, 115, 120
 - fuzzy subtraction, 113, 120
- Fuzzy c-means (FCM), 23, 49, 66–68, 160–161
- Fuzzy c-means-particle swarm
 - optimisation (FCM-PSO), 68–69
- Fuzzy calculator, 141
- Fuzzy CDF. *See* Fuzzy cumulative distribution function (fuzzy CDF)
- Fuzzy clustering, 66
 - fuzzy c-means (FCM) clustering, 66–70
 - subtractive clustering, 66–67
 - See also* Clustering
- Fuzzy cognitive map (FCM), 414–416
 - enhancing CM tools and practices with, 417–419
 - modelling, 419–423
- Fuzzy composition, 15–16
 - Fuzzy consensus, 232–234, 242, 263–266, 270–271
 - See also* Consensus
- Fuzzy consensus qualitative risk
 - analysis framework (FCQRA framework), 265
- Fuzzy consensus-reaching process, 233, 234, 263
- building design applications, 264
- consensus measures, 236
- construction
 - bidding applications, 268–269
 - procurement and project delivery applications, 266–267
 - productivity applications, 269–270
- importance degree of experts, 234–235
- for MCGDM problems, 236–242
- mechanism adopting to guide discussion process, 234
- preference representation formats, 235–236
- risk analysis and hazard assessment applications, 265–266
- Fuzzy cumulative distribution function (fuzzy CDF), 84
- Fuzzy database, 384
- Fuzzy datacube, 363
- Fuzzy discrete event simulation (FDES), 84, 88–90, 142, 151, 157–159, 167
- Fuzzy distance measurement method (FDMM), 265
- Fuzzy domain, 19–20
- Fuzzy enabled GA-PSO method (FEGA-PSO), 51
- Fuzzy evaluation vector of RM capability, 348–349
- Fuzzy extensions of AHP, 280
 - consistency of fuzzy pairwise comparisons, 284–285
 - fuzzy pairwise comparisons, 281–284
 - fuzzy weights and defuzzification, 285–288
- Fuzzy feedback models, 420
- Fuzzy hybrid machine learning, 52, 92–93
 - fuzzy clustering techniques, 66–70
 - hybridisation of fuzzy logic with ANN technique, 52, 63–66

- papers for fuzzy hybrid machine learning techniques in construction, 53–62
- techniques, 38
- Fuzzy hybrid modelling in construction, 29–30
- Fuzzy hybrid optimization, 41, 92
 - fuzzy hybrid evolutionary models, 43, 48–49
 - fuzzy hybrid particle swarm optimization models, 50–52
 - models, 38
 - papers for fuzzy hybrid optimization models in construction, 44–47
- Fuzzy hybrid particle swarm optimization models, 50–52
- Fuzzy hybrid techniques
 - in construction engineering and management
 - future research directions, 94–96
 - fuzzy multi-criteria decision-making, 70–83, 93–94
 - fuzzy simulation, 83–92, 94
 - systematic literature review methodology, 39–41
 - in construction risk analysis, 308
- Fuzzy inference system (FIS), 24, 453, 469
 - See also* Fuzzy expert system (FES); Fuzzy rule-based system (FRBS); Mamdani inference; Mamdani-type fuzzy inference system; Sugeno inference; Sugeno fuzzy inference system; Sugeno-type fuzzy inference system
- Fuzzy intersection, 14
- Fuzzy linear programming technique for multi-dimensional analysis of preference (FLINMAP), 83
- Fuzzy linguistic terms, 266
- Fuzzy logic (FL), 38, 151, 305–308, 359, 362, 417, 453
 - integration and simulation techniques, 157
 - fuzzy agent-based modelling, 162–167
 - fuzzy DES, 157–159
 - fuzzy system dynamics, 159–162
- Fuzzy machine learning techniques, 30, 157, 159–163, 166, 173
- Fuzzy membership functions, 49, 65–66, 84, 460–462
- Fuzzy Monte Carlo simulation (FMCS), 84, 88, 306
- Fuzzy multi-criteria decision-making (FMCDM), 38, 70, 93–94
 - fuzzy AHP, 70, 78–79
 - fuzzy TOPSIS, 80–81
 - fuzzy VIKOR, 82–83
 - methods, 186, 267
 - methods and applications, 197
 - in construction management, 197–220
 - FS-based MCDM methods and applications, 197–205
 - HFS-based MCDM methods and applications, 210–214
 - IFS-based MCDM methods and applications, 205–210
 - linguistic variables, 427
 - relationships for significant first-time events, 428–430
 - T2FS-based MCDM methods and applications, 214–220
- papers for fuzzy multi-criteria decision-making (MCDM) techniques in construction, 71–77
 - See also* Group decision-making process (GDM process); Multi-criteria decision-making (MCDM); Multi-criteria group decision-making problems (MCGDM problems)
- Fuzzy multi-dimensional structure, 359, 362–364, 367
 - company, 374–375
 - construction organisations, 367–368

- construction type, 371–372
- dimensions, 369
- injury, 378–379
- location, 375–376
- project, 370–371
- promoter, 374
- task, 372–374
- time, 369–370
- worker, 377–378
- Fuzzy negative ideal solution (FNIS), 258, 269
- Fuzzy neural networks (FNNs), 52
- Fuzzy number induced ordered weighted averaging (FN-IOWA), 232, 248–251
- Fuzzy numbers, 18–20, 91, 112–113
- Fuzzy optimal aggregation method (FOAM), 265
- Fuzzy pairwise comparison
 - check for consistency of, 290
 - matrices, 289–290
- Fuzzy partitions, 13–14
- Fuzzy positive ideal solution (FPIS), 258, 269
 - See also* Preference relations
- Fuzzy preference relation consensus approach (FPRC approach), 267
- Fuzzy prioritised weighted aggregation operators, 251–257
- Fuzzy prioritised weighted averaging operator (FPWA operator), 252
- Fuzzy RA decision-making process, 343
- Fuzzy random
 - approach, 51
 - multi-objective decision-making model, 50–51
 - variables, 48, 88
- Fuzzy ranking method, 89, 158, 198, 199
- Fuzzy relational matrix, 347–348
- Fuzzy relations, 15–16
- Fuzzy risk allocation methodology, 345–351
- Fuzzy rule-based systems (FRBS), 3, 24–25, 27–29, 42–43, 235
 - See also* Fuzzy inference system (FIS); Fuzzy rule-based system (FRBS); Mamdani inference; Mamdani-type fuzzy inference system; Sugeno inference; Sugeno fuzzy inference system; Sugeno-type fuzzy inference system
- Fuzzy set theory (FST), 5–6, 185–186, 192, 231, 232, 339
 - HFSs, 194–195
 - IFSs, 193–194
 - T2FSs, 195–197
- Fuzzy set-based analytic hierarchy process, 198–200
- Fuzzy set-based elimination and choice expressing reality, 202
- Fuzzy set-based MCDM methods and applications, 197
 - analytic hierarchy process, 198–200
 - elimination and choice expressing reality, 202
 - F-MCDM method applications in construction management, 203–205
 - F-PROMETHEE, 203
 - technique for order of preference, 200–202
 - weighted sum method, 197–198
- Fuzzy set-based preference ranking
 - organisation method enrichment evaluation (F-PROMETHEE), 203
- Fuzzy sets, 7–17, 342, 358, 417
- Fuzzy similarity aggregation method (FSAM), 265
- Fuzzy similarity consensus model (FSC model), 267
- Fuzzy simulation, 38, 83–92, 94, 112–113

- in construction, 151–155, 167–171
- FDES, 88–90
- FMCS, 84, 88
- FSD, 90–91
- fuzzy ABM, 91–92
- integrating fuzzy logic and, 157–167
- limitations, 155–157
- papers for fuzzy simulation
 - techniques in construction, 85–87
- Fuzzy synthetic evaluation (FSE), 339, 342, 343
- Fuzzy system dynamics (FSD), 84, 90–91, 151, 159–162
 - applications, 168–170
 - model of quality management practice, 168–170
- Fuzzy technique for order of preference by similarity to ideal solution (Fuzzy TOPSIS), 70, 80–81, 232
 - fuzzy TOPSIS-based approach, 263
 - for prioritised aggregation, 257–263
- Fuzzy TOPSIS. *See* Fuzzy technique for order of preference by similarity to ideal solution (Fuzzy TOPSIS)
- Fuzzy upper and lower project management costs, 324
- Fuzzy variables, 13–14, 156
- Fuzzy vector, 343, 349
- Fuzzy VIKOR, 82–83
- Fuzzy weighted aggregation, 239
- Fuzzy weighted average (FWA), 232, 245–246
 - aggregation method, 268
- Fuzzy weighted mean. *See* Fuzzy weighted average (FWA)
- FWA. *See* Fuzzy weighted average (FWA)
- GA. *See* Geometric averaging (GA)
- GA-PSO. *See* Genetic algorithms with particle swarm optimisation (GA-PSO)
- Gabi software package, 306
- GA. *See* Genetic algorithms (GA)
- Gaussian function, 394
- GDM process. *See* Group decision-making process (GDM process)
- Generalised PA operators (GPA operators), 252
- Generalised POWA operators (GPOWA operators), 252
- Genetic algorithms (GA), 43, 157
- Genetic algorithms with particle swarm optimisation (GA-PSO), 51
- Genetic fuzzy systems, 163, 393
- Geometric averaging (GA), 242–243
- Geometric mean method, 285
- Ghana's water sector, 339
- GLNPSO-based FRS. *See* Global-local-neighbour PSO with fuzzy random simulation (GLNPSO-based FRS)
- Global urban rate, 185
- Global-local-neighbour PSO with fuzzy random simulation (GLNPSO-based FRS), 50
- Goal commitment, 156
- GPA operators. *See* Generalised PA operators (GPA operators)
- GPOWA operators. *See* Generalised POWA operators (GPOWA operators)
- Grade of membership. *See* Membership functions
- Group decision-making process (GDM process), 231
- Hazard assessment applications, 265–266
- Health and Safety Executive (HSE), 326
- Health, safety and environment (HSE), 311
- Hesitant fuzzy element (HFE), 195
- Hesitant fuzzy sets (HFSs), 193, 194–195

- HFS-based MCDM methods and applications, 210
- HF-MCDM methods and applications in construction management, 214
- HFS-based analytic hierarchy process, 210–211
- HFS-based elimination and choice expressing reality, 213–214
- HFS-based technique for order of preference, 212–213
- Hesitant fuzzy sets-based analytic hierarchy process, 210–211
- Hesitant multiplicative programming method (HMPM), 210
- Heterogeneous group, 235
- Heuristic optimization technique, 42
- HFE. *See* Hesitant fuzzy element (HFE)
- HFSs. *See* Hesitant fuzzy sets (HFSs)
- Hierarchical structure, 422
- High dimensionality, 95
- High RM capability, 342
- High-performance concrete (HPC), 64
- HMPM. *See* Hesitant multiplicative programming method (HMPM)
- Horizontal methods, 20–21
- HPC. *See* High-performance concrete (HPC)
- HSE. *See* Health and Safety Executive (HSE); Health, safety and environment (HSE)
- Human motion, 452
- Hybrid computing techniques, 392, 393
- Hybrid fuzzy approach, 453
- Hybrid genetic algorithm (GA)-NNDFR technique, 65
- Hybrid methods, 30
- Hybrid neuro-fuzzy systems, 52, 63
- Hybridization, 38
 - of fuzzy logic, 52
 - with ANN technique, 52, 63–66
 - with clustering techniques, 23–24, 49, 52, 66–70, 93, 94–95
 - with machine learning techniques, 30, 38, 52, 92, 94–95
 - with MCDM techniques, 38, 70
 - with optimization techniques, 42
 - with simulation techniques, 83–84, 91, 94, 95
 - of fuzzy methods, 92
- I-IOWA. *See* Importance IOWA (I-IOWA)
- Idempotence, 244
- IF-MCDM. *See* Intuitionistic fuzzy-multi-criteria decision-making (IF-MCDM)
- IFSs. *See* Intuitionistic fuzzy sets (IFSs)
- IFWA operator. *See* Intuitionistic fuzzy weighted average operator (IFWA operator)
- Importance IOWA (I-IOWA), 249
- Incompatibility, 13
- Index of optimism, 287
- Induced ordered weighted averaging (IOWA), 248–249
- Inference process, 26
- Information systems (ISs), 358
- Information technologies, 358
- Infrastructure projects, 414
- Injury dimension hierarchy, 378–379
- Input selection, 396–397
- INSHT. *See* Spanish National Institute for Safety and Hygiene at Work (INSHT)
- Intelligent computing layer on traditional tools, 422
- Intelligent decision support systems, 419
- Intelligent modelling, 414
- Intersection of fuzzy sets, 14
- Intersection operations, 14
- Interval type-2 fuzzy sets (IT2FSs), 196
- Intuitionistic fuzzy sets (IFSs), 193–194
 - IFS-based MCDM methods and applications, 205
 - IF-MCDM method and applications in construction management, 210

- IFS-based analytic hierarchy process, 205–206
- IFS-based elimination and choice expressing reality, 207–209
- IFS-based PROMETHEE, 209–210
- IFS-based technique for order of preference, 206–207
- Intuitionistic fuzzy weighted average operator (IFWA operator), 268
- Intuitionistic fuzzy-multi-criteria decision-making (IF-MCDM), 197
 - applications in construction management, 221
 - method and applications in construction management, 210
- IOWA. *See* Induced ordered weighted averaging (IOWA)
- ISs. *See* Information systems (ISs)
- IT2FS. *See* Interval type-2 fuzzy sets (IT2FSs)
- Iterative algorithms, 234
- Jacobian matrices, 457
- Kalman filter(ing), 453, 457
 - extended Kalman filter, 456–458
 - motion trajectory tracking, 453
 - nonlinear Kalman filtering, 466
 - sensor fusion method, 470
 - unscented Kalman filter, 456, 458–460
- Kernel functions, 394, 400–401
- Kinect visual camera, 453, 456, 466
 - motion capture with, 463–465
- Kinship relation, 363, 370
- Knowledge representation techniques, 421
- L-R fuzzy numbers, 19
- Labour, 170–171
- Largest of maxima (LOM), 162
- Law of Cosine, 464
- LCB. *See* Low-carbon building (LCB)
- Least square method, 390
- Level of confidence, 79, 287
- Linear programming, 42, 92, 211, 308
- Linguistic F-Cube Factory, 364
- Linguistic hedges, 15
- Linguistic labels, 377
- Linguistic modifiers, 15
- Linguistic ordered weighted averaging (LOWA), 232, 246–248
- Linguistic variables, 343, 346, 347, 358
- Liquefied natural gas (LNG), 80
- Ljung-Box Q-statistics, 398
- LNG. *See* Liquefied natural gas (LNG)
- Local and global weights of criteria and sub-criteria, 290–293
- Location dimension hierarchy, 375–376
- Logistics rules, 421
- LOM. *See* Largest of maxima (LOM)
- Loose volume, 143
- Low price, 7
- Low RM capability, 342
- Low-carbon building (LCB), 186
- LOWA. *See* Linguistic ordered weighted averaging (LOWA)
- Lukasiewicz *t*-norm. *See* Bounded difference *t*-norm
- MA model. *See* Moving average model (MA model)
- Machine learning, 52
- MAE. *See* Mean absolute error (MAE)
- Mamdani inference, 26, 27
 - See also* Fuzzy expert system (FES); Fuzzy inference system (FIS); Fuzzy rule-based system (FRBS); Mamdani-type fuzzy inference system
- Mamdani-type fuzzy inference system, 460
 - See also* Fuzzy expert system (FES); Fuzzy inference system (FIS); Fuzzy rule-based system (FRBS); Mamdani inference

- MAPE. *See* Mean absolute percentage error (MAPE)
- Mathematical methods, 112
- consecutive fuzzy arithmetic operations, 116
 - for implementation of extended fuzzy arithmetic, 116–119
 - implementation of standard fuzzy arithmetic, 113–116
- MATLAB program, 470
- Max-min composition, 16
- Maxima methods, 286–287
- MCDM. *See* Multi-criteria decision-making (MCDM)
- MCGDM problems. *See* Multi-criteria group decision-making problems (MCGDM problems)
- MCS. *See* Monte Carlo simulation (MCS)
- ME design. *See* Mechanistic-empirical design (ME design)
- Mean absolute error (MAE), 64
- Mean absolute percentage error (MAPE), 397, 398
- Mean aggregation operator, 269–270
- Mean of maxima (MOM), 17
- Mean square error (MSE), 29, 64
- Mechanistic-empirical design (ME design), 68
- Median of area (MOA), 16
- Medium, 12
- Medium price, 7
- Membership function specification methods, 20
- based on clustering, 23–24
 - horizontal method, 20–21
 - pairwise comparison using analytic hierarchy process, 21–22
 - statistical methods, 22–23
 - vertical method, 20–21
- Membership function, 7, 159–160, 346–347, 461–462
- basic set operations on fuzzy sets, 14–15
 - characteristics, 11–13
 - defuzzification, 16–17
 - fuzzy relations and fuzzy composition, 15–16
 - fuzzy variables and fuzzy partitions, 13–14
 - representing membership functions, 9–10
 - See also* Fuzzy membership functions
- Metaheuristic optimization technique, 42
- Microsoft Kinect motion camera, 463
- Middle of maxima (MOM), 162
- Min t -norm, 116
- MOA. *See* Median of area (MOA)
- Model-based clustering technique, 67
- Moderate RM capability, 342
- Moderator, 231–232
- MOM. *See* Mean of maxima (MOM); Middle of maxima (MOM)
- Monotonicity property, 244
- Monte Carlo simulation (MCS), 82, 151, 306, 314, 458
- Motion capture, 463–465
- Motion sensing system, 452
- Motion trajectory tracking, 453
- Moving average model (MA model), 393
- MRC. *See* Multimode resource-constrained (MRC)
- MSE. *See* Mean square error (MSE)
- Multi-attribute utility function, 235
- Multi-criteria analysis methods, 313–314
- Multi-criteria decision-making (MCDM), 38, 185–186
- methods, 70, 280
 - process, 264
 - process and methods, 186
 - AHP, 189
 - ANP, 190
 - in construction management, 186–192
 - ELECTRE method, 191
 - PROMETHEE, 192

- TOPSIS, 190–191
- WSM, 188–189
- Multi-criteria group decision-making problems (MCGDM problems), 231, 232, 235
 - fuzzy aggregation processes, 242–263
 - fuzzy consensus reaching and aggregation, 263–270
 - fuzzy consensus-reaching process, 233–242
- Multi-dimensional structure, 359
 - DW, 359–360
 - fuzzy logic, 362
 - operations, 360–362
- Multi-linear regression, 64
- Multi-nonlinear regression, 64
- Multimode resource-constrained (MRC), 49
- Multivariate models, 391
- Myo armband sensor, 453, 466
 - motion capture with, 463–465
- Myo motion sensor, 455
- Negative ideal solution (NIS), 257–258
 - distances of weighted normalised collective evaluations, 262
- Net present value (NPV), 311
- Neural-network-driven fuzzy reasoning technique (NNDFR technique), 65
- Neuro-fuzzy hybrid models, 308
- Newton–Euler equations, 454
 - Newton–Euler equation-based dynamics, 453
- NIS. *See* Negative ideal solution (NIS)
- NMAE. *See* Normalised mean absolute error (NMAE)
- NNDFR technique. *See* Neural-network-driven fuzzy reasoning technique (NNDFR technique)
- Non-convex fuzzy set, 12–13
- Nonlinear Kalman filtering methods, 466
- Nonlinear Kalman filtering-based gesture tracking, 453, 456–457
- Nonlinear models, 393
- Nonlinear system dynamics, 454–457
- Normalised mean absolute error (NMAE), 398
- Normalised weight distribution, 318
- NPV. *See* Net present value (NPV)
- Object hierarchies, 421
- ODC. *See* Overall degree of consensus (ODC)
- Offline FCM modelling, 415
- Oil drilling
 - application of fuzzy AHP techniques in, 310
 - case study, 311–312
 - ERD well solution, 312
 - mapping project initiation stage, 310
 - subsea solution, 312, 313
- On line analytical processing (OLAP), 358, 360
- Operating expenditure (OPEX), 313
- Optimization, 41–43, 48, 92
- Optimisation algorithms, 234
- Optimum system hierarchy analysis, 42
- Ordered weighted averaging (OWA), 242–243, 246–247
- Organisational complexity
 - contours of global weights for sub-criteria within, 293
 - fuzzy pairwise comparison matrix of sub-criteria within, 292
 - pairwise comparisons by experts with regard to, 291
- Out-of-sample forecast, 401
- Overall degree of consensus (ODC), 240
- OWA. *See* Ordered weighted averaging (OWA)
- P-IOWA. *See* Preference IOWA (P-IOWA)

- PA operators. *See* Prioritised averaging operators (PA operators)
- Pairwise comparison, 291, 322
 using analytic hierarchy process, 21–22
 consistency of fuzzy, 284–285
 fuzzy, 281–284
- Pareto-optimal set, 49
- Particle swarm optimization (PSO), 42–43, 157
- Particles, 50
- Partitional k -means clustering, 66–67
- Percentage error metrics, 398
- PIS. *See* Positive ideal solution (PIS)
- Pivot operation, 362
- Planning, 421
 analysis, 366–367, 369, 379
- PM. *See* Project management (PM)
- PM–FCM model. *See* Project management–fuzzy c-means model (PM–FCM model)
- Positive ideal solution (PIS), 257–258
 distances of weighted normalised collective evaluations to, 262
- Post-mortem analysis, 416
- POWA operators. *See* Prioritised OWA operators (POWA operators)
- PPPs. *See* Public–private partnerships (PPPs)
- Prediction modelling, 396–397
- Preference IOWA (P-IOWA), 249
- Preference ranking organisation method for enrichment evaluation (PROMETHEE), 7, 185–186, 192
 See also T2FS-PROMETHEE
- Preference relations, 192, 203, 209, 210, 235–236, 249, 265
 linguistic preference relations, 235–236
 multiplicative preference relations, 235
 See also Fuzzy preference relations
- Preference representation formats, 235–236
- Prioritised averaging operators (PA operators), 252
- Prioritised OWA operators (POWA operators), 252
- Probabilistic distributions, 84, 156, 158
- Probabilistic values, 155
- Probabilistic variable, 150, 151, 156, 157, 162
- Probability theory, 6
- Production risk for subsea option, 315–318
- Productivity, 5, 9, 25, 28, 42, 65, 91, 93
- Project, 370–371
 complexity, 279, 293–295
 framework for measuring, 288
 hierarchical structure, 288–289
 delivery applications, 266–267
 dimension hierarchy, 371
 performance, 168–169, 266, 270, 279–280, 293–295
 PPP, 288
 project-execution risks, 418
 pursuit process, 415
 risk analysis in, 305–310
- Project management (PM), 374, 423–436
- Project management–fuzzy c-means model (PM–FCM model), 424
- PROMETHEE. *See* Preference ranking organisation method for enrichment evaluation (PROMETHEE)
- Promoter, 374, 375
- PSO. *See* Particle swarm optimization (PSO)
- Public–private partnerships (PPPs), 338
 case study, 343–344
 decision criteria for defining RM capability, 341, 342
 fuzzy risk allocation methodology, 345–351
 fuzzy synthetic evaluation and risk allocation, 342–343
 practitioners’ feedback on methodology, 351

- previous studies on risk allocation in, 339–341
- projects, 288
- round three of Delphi survey for risk allocation, 344
- two-round Delphi survey for risk allocation decision criteria, 344
- Pursuit review items, 418
- QFD. *See* Quality function deployment (QFD)
- Quadratic programming models, 234
- Qualitative criteria, 80
- Qualitative knowledge, 308
- Quality function deployment (QFD), 204
- Quality management practices, 169
- Quantitative criteria, 80
- Quantitative knowledge, 308
- R-code, 400
 - for ANFIS, 410–411
- RA. *See* Risk allocation (RA)
- Radial basis function (RBF), 394
 - kernel, 401
- Random index (RI), 284
- RBF. *See* Radial basis function (RBF)
- Real-world systems, 155
- Reciprocal matrix, 22
- Relative closeness index, 257–258
- RI. *See* Random index (RI)
- Risk, 305
- Risk allocation (RA), 338
 - decision, 350–351
 - fuzzy synthetic evaluation and, 342–343
 - previous studies in PPPs, 339–341
 - round three of Delphi survey, 344
 - two-round Delphi survey, 344
- Risk analysis, 305
 - in projects, 305
 - FL, 306–308
 - fuzzy AHP in, 308–310
 - fuzzy hybrid techniques, 308
 - MCS, 306
- Risk management (RM), 339
 - decision criteria for defining RM capability, 341, 342
 - fuzzy evaluation vector of RM capability, 348–349
 - processes, 305
 - responsibility, 340
- RM. *See* Risk management (RM)
- RMSE. *See* Root mean square error (RMSE)
- Robotic manipulator modelling of arm gestures, 453
 - dynamic modelling of arm gestures, 453–454
 - EKF, 457–458
 - nonlinear system dynamics, 454–457
 - UKF, 458–460
- Robust visual sensing technology, 452
- Roll-up operation, 360–361
- Root mean square error (RMSE), 64, 466
- Round three of Delphi survey for risk allocation, 344
- s*-norm, 14
 - algebraic sum, 15, 26
 - bounded sum, 15
 - drastic union, 15
 - max *s*-norm. *See* Standard union
 - s*-norm
 - standard union, 15
 - See also* Triangular-conorm (*t*-conorm)
- SAA. *See* Scalable algorithm of aggregation (SAA)
- Safety analysis, 365–366
- Safety management, 374, 376
- SAM. *See* Similarity aggregation method (SAM)
- Scalable algorithm of aggregation (SAA), 242–243
- SD. *See* System dynamics (SD)
- Season, 369
- Selection process, 233–234
- Sensitivity analysis, 405

- Sensor fusion methods, 453, 456–457
- Sensor-based approaches, 366
- Serial correlation, 398
- Service hierarchy, 377
- Shannon entropy concept, 287
- Similarity aggregation method (SAM), 232
- Simple cause-and-effect analysis, 424
 - CM–FCM relationships for
 - significant first-time events, 428–430
 - concepts in CM and PM, 425–426
 - linguistic variables in CM–FCM, 427
 - multiple scenarios, 431–432
- Simulation
 - limitations, 155–157
 - techniques, 150, 151, 157–167
 - in construction, 151–155*See also* Fuzzy simulation
- Simulink program, 470
- Single subsea well, 312, 313
- Slice operation, 361
- Smallest of maxima (SOM), 162
- Social criteria, 78–79
- Soft computing techniques, 414–415, 419
- SOM. *See* Smallest of maxima (SOM)
- Spanish National Institute for Safety and Hygiene at Work (INSHT), 379
- SPEA. *See* Strength Pareto evolutionary algorithm (SPEA)
- Squared error metrics, 398
- SRLP. *See* Success rate of learner phase (SRLP)
- SRTP. *See* Success rate of teacher phase (SRTP)
- Stakeholders, 390
- Standard fuzzy arithmetic, 113
 - implementation, 113–116, 121–123
- Standard intersection t -norm, 14
- Standardised trapezoidal fuzzy numbers (STFNs), 265
- Standards for technical condition
 - evaluation of highway bridges (STCEHB), 69
- Statistical methods, 22–23
- Statistical-based aggregation operators
 - and algorithms, 242–243
- STCEHB. *See* Standards for technical condition evaluation of highway bridges (STCEHB)
- STFNs. *See* Standardised trapezoidal fuzzy numbers (STFNs)
- Stocks, 153
- Strength Pareto evolutionary algorithm (SPEA), 48–49
- Subjective reasoning, 5
- Subjective uncertainty, 30, 42, 43, 51, 52, 63
- Subsea solution, 312, 313
- Subtractive clustering, 67
- Success rate of learner phase (SRLP), 42–43
- Success rate of teacher phase (SRTP), 42–43
- Sugeno fuzzy inference system, 394
 - See also* Fuzzy expert system (FES); Fuzzy inference system (FIS); Fuzzy rule-based system (FRBS); Sugeno inference; Sugeno-type fuzzy inference system
- Sugeno inference, 26, 27
 - See also* Fuzzy expert system (FES); Fuzzy inference system (FIS); Fuzzy rule-based system (FRBS); Sugeno fuzzy inference system; Sugeno-type fuzzy inference system
- Sugeno-type fuzzy inference system, 460–463, 470
 - See also* Fuzzy expert system (FES); Fuzzy inference system (FIS); Fuzzy rule-based system (FRBS); Sugeno inference; Sugeno fuzzy inference system
- Supplier selection, 78

- Support vector machine model (SVM model), 391, 394, 400–401
- Symbolic representation, 423
- System dynamics (SD), 83–84, 152–153
- Systematic literature review methodology, 39–41
- t*-norm
 - algebraic product, 124–131
 - Archimedean, 117–118
 - bounded difference, 131–136
 - drastic product, 137–141
 - Lukasiewicz *t*-norm. *See* Bounded difference *t*-norm
 - min *t*-norm. *See* Standard intersection *t*-norm
 - operator, 117
 - standard intersection, 116
- T2FS-based MCDM methods and applications, 214–220
- analytic hierarchy process, 215–216
- PROMETHEE, 219
- T2FS-MCDM method applications, 219–220
- technique for order of preference, 216–218
- weighted product method, 215
- weighted sum method, 214–215
- T2FS-PROMETHEE, 179, 220
- T2FS-TOPSIS, 179, 218
- trapezoidal, 216–217
- T2FSs. *See* Type-2 fuzzy sets (T2FSs)
- Takagi-Sugeno-Kang-type fuzzy inference system. *See* Sugeno-type fuzzy inference system
- TBM. *See* Tunnel boring machine (TBM)
- Teaching-learning-based optimization (TLBO), 42–43
- Team agent, 166
- Technique for order of preference by similarity to ideal solution (TOPSIS), 70, 186, 190–191
See also T2FS-TOPSIS
- Tender price index, 390, 402
- Tender price index forecasting, 390, 392, 396
 - univariate modelling techniques application in, 391–393
- TFLPWA operator. *See* Trapezoidal fuzzy linguistic prioritised weighted average operator (TFLPWA operator)
- TFN. *See* Triangular fuzzy numbers (TFNs)
- Theil's inequality coefficient, 397
- THFSs. *See* Typical hesitant FSs (THFSs)
- Time dimension, 369–374
- Time paradox, 89
- Time series
 - forecasting, 392
 - modelling techniques, 390, 398
- Time-cost optimisation model, 308
- TLBO. *See* Teaching-learning-based optimization (TLBO)
- TnFSs. *See* Type-n FSs (TnFSs)
- Tolerance, 321
 - factor, 310, 324
- TOPSIS. *See* Technique for order of preference by similarity to ideal solution (TOPSIS)
- Traditional human-centred decision-making process, 367
- Trapezoidal fuzzy linguistic prioritised weighted average operator (TFLPWA operator), 252
- Trapezoidal fuzzy number, 19
- Trapezoidal membership function, 10
- Triangular fuzzy membership function, 264
- Triangular fuzzy numbers (TFNs), 81, 120, 137, 193, 283
- Triangular-conorm (*t*-conorm). *See* *s*-norm
- Triangular-norm operators, 14
- Trym field, 311
- Tunnel boring machine (TBM), 89

- Two-round Delphi survey for risk allocation decision criteria, 344
- Two-stage classification approach, 452
- Type-2 fuzzy sets (T2FSs), 192–193, 195–197
 - See also* T2FS-based MCDM methods and applications
- Type-n FSs (TnFSs), 192–193
- Typical hesitant FSs (THFSs), 195
- UKF. *See* Unscented Kalman filter (UKF)
- UMF. *See* Upper membership function (UMF)
- UML. *See* Unified modelling language (UML)
- Unanimity. *See* Idempotence
- Uncertainty
 - ambiguity, 5, 29–30, 82, 206, 214, 231, 305
 - non-probabilistic, 30, 155
 - probabilistic, 84, 88, 94, 156–157
 - random, 48, 51, 95, 155
 - subjectivity, 5, 29–30, 82
 - vagueness, 5, 29–30, 82, 206, 305
- Unified modelling language (UML), 164
- Union of fuzzy sets, 18
- Union operations, 14
- Univariate models, 391, 393
 - application, 398–401
 - modelling techniques, 393
 - ANFIS, 394–395
 - application in tender price index forecasting, 391–393
 - Box–Jenkins model, 393
 - SVM model, 394
- Unscented Kalman filter (UKF), 456, 458–460
- Upper membership function (UMF), 196
- Urbanisation process, 185
- Vague funny sets (VFSs), 193
- Vector diagram for angle calculation, 465
- Vector3D class, 464
- Vertical methods, 20–21
- VFSs. *See* Vague funny sets (VFSs)
- Virtual designs, 366
- Visekriterijumska optimizacija i Kompromisno Resenje (VIKOR), 70
 - fuzzy, 82–83
- WAA. *See* Weighted arithmetic averaging (WAA)
- WBS. *See* Work breakdown structure (WBS)
- Weigh-in-motion (WIM), 68
- Weighted arithmetic averaging (WAA), 242–243
- Weighted geometric averaging (WGA), 242–243
- Weighted mean model, 349
- Weighted normalised fuzzy decision matrix (WNFDM), 269
- Weighted sum method (WSM), 188–189
- Weighting function set of decision criteria, 346
- WGA. *See* Weighted geometric averaging (WGA)
- WIM. *See* Weigh-in-motion (WIM)
- WNFDM. *See* Weighted normalised fuzzy decision matrix (WNFDM)
- Work accidents, 379
 - datacube, 368
- Work breakdown structure (WBS), 372–374
- Work development, 368, 379, 380
- Worker dimension hierarchy, 377–378
- Worker's commitment, 150
- Workplace safety, 365
- WSM. *See* Weighted sum method (WSM)
- Zero-order Sugeno fuzzy model, 463