## Contents

<table>
<thead>
<tr>
<th>Acknowledgements</th>
<th>XXIX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preface</td>
<td>XXXI</td>
</tr>
<tr>
<td>Conversion table</td>
<td>XXXV</td>
</tr>
</tbody>
</table>

### 1 Introduction

1.1 Excavations and their classification  
1.2 Surface excavations  
1.3 Underground excavations  
1.4 Importance of minerals and brief history of their recovery  
1.5 Current status of mineral industry  
1.6 Excavation technologies/systems – development & growth  
1.7 Unique features of mineral industry  
  1.7.1 Different phases of mine life  
1.8 Brief history of civil work excavations including tunneling  
1.9 The current scenario  
  1.9.1 Population growth  
  1.9.2 Lifestyle  
  1.9.3 Globalization  
  1.9.4 Buyer’s market  
  1.9.5 Technological developments and renovations  
  1.9.6 Information technology (IT) and its impacts  
1.10 Tomorrow’s mine & civil excavations  
1.11 The way forward  
  Questions  
  References  

### 2 Rocks, minerals and mineral inventory evaluation

2.1 Formation process and classification  
  2.1.1 Igneous rocks  
  2.1.2 Sedimentary rocks  
  2.1.3 Metamorphic rocks  
2.2 Rock cycle & type of deposits  
2.3 Texture, grain size and shape  
  2.3.1 Grain sizes and shapes  
  2.3.2 Durability, plasticity and swelling potential of rocks
2.4 The concepts of mineral resources and reserves; mineral inventory, cutoff grade and ores
  2.4.1 Some important ores – chemical & mineralogical composition 32
2.5 Geological structures 32
  2.5.1 Geometry of a deposit 32
  2.5.2 Forms of deposits 34
  2.5.3 Structural features of rock mass 34
2.6 Physical and mechanical characteristics of ores and rocks 37
  2.6.1 Rocks as rock mechanics 37
  2.6.2 Rock composition 38
  2.6.3 Rock strength 40
2.7 Some other properties/characteristics 41
  2.7.1 Hardness of minerals 41
  2.7.2 Rock breakability 42
2.8 Related terms – rock and mineral deposits 43
2.9 Mineral inventory evaluation 45
  2.9.1 Introduction 45
  2.9.2 Grade computation from borehole data 46
  2.9.3 Mineral inventory modelling/estimation techniques 46
    2.9.3.1 Method of polygons 47
    2.9.3.2 Triangle or triangular prism method 48
    2.9.3.3 Cross-sectional method 49
    2.9.3.4 Inverse Square Distance Weighting (IDW) method 50
    2.9.3.5 Classical statistics 50
    2.9.3.6 Geostatistics 50
    2.9.3.7 Non-linear estimation techniques in geostatistics 51
  2.9.4 Important considerations for evaluation of the mineral inventory 53
    2.9.4.1 Homogeneity and mode of origin 53
    2.9.4.2 Geological and mineralogical boundaries 53
  2.9.5 Computation of the mineral inventory 55
    2.9.5.1 Logical steps followed 55
    2.9.5.2 Graphical presentation of data 55
    2.9.5.3 Statistical analysis and cumulative probability distribution 56
    2.9.5.4 Structural analysis – the semi-variogram 56
    2.9.5.5 Trend surface analysis 57
    2.9.5.6 Checking the variogram model 57
    2.9.5.7 Block kriging 57
    2.9.5.8 Block dimensions 57
    2.9.5.9 Kriging procedure 58
  2.9.6 Graphical presentation of the kriged results 58
  2.9.7 Grade-tonnage calculation and plotting the curves 60
  2.9.8 Selection of a suitable mining/stoping method 61
2.10 Resources classification by UNECE 62
2.11 The way forward
  Questions 66
  References 69
3 Prospecting, exploration & site investigations

3.1 Introduction

3.2 Prospecting and exploration

3.2.1 Finding signs of the mineral in the locality or general indications

3.2.1.1 Geological studies

3.2.1.2 Geo-chemical studies

3.2.2 Finding the deposit or preliminary proving

3.2.2.1 Geophysical methods/studies/surveys

3.2.2.2 Putting exploratory headings

3.2.3 Exploring the deposits or detailed proving – prospecting drilling

3.3 Phases of prospecting and exploration program

3.4 Site investigations for civil constructions, or any excavation project including tunnels and caverns

3.5 Rocks and ground characterization

3.5.1 Rock strength classification

3.5.2 Rock mass classifications

3.6 Rock quality designation (RQD)

3.6.1 Q (Rock mass quality) system

3.6.2 Geomechanics classification (RMR system)

3.6.3 Rock structure rating (RSR)

3.7 Geological and geotechnical factors

3.8 The way forward

Questions

References

4 Drilling

4.1 Introduction – unit operations

4.2 Primary rock breaking

4.3 Drilling

4.4 Operating components of the drilling system

4.5 Mechanics of rock penetration

4.5.1 Top-hammer drilling

4.5.2 Down-the-hole (DTH) drilling

4.5.3 Rotary drilling

4.5.4 Augur drill

4.5.5 Rotary abrasive drilling

4.6 Rock drill classification

4.6.1 Tunneling/development drill jumbos

4.6.2 Shaft jumbos

4.6.3 Ring drilling jumbos

4.6.4 Fan drilling jumbos

4.6.5 Wagon drill jumbos

4.6.6 DTH drill jumbos

4.6.7 Roof bolting jumbos
4.7 Motive power of rock drills  
4.7.1 Electric drills  
4.7.2 Pneumatic drills  
4.7.3 Hydraulic drills  
4.8 Drilling accessories  
4.8.1 Extension drill steels  
4.8.2 Bits  
4.8.3 Impact of rock-type on drilling performance  
4.9 Selection of drill  
4.10 Summary – rocks drill applications  
4.11 Drilling postures  
4.12 The way forward  
Questions  
References  

5 Explosives and blasting  
5.1 Introduction – explosives  
5.2 Detonation and deflagration  
5.3 Common ingredients of explosives  
5.4 Classification of explosives  
5.4.1 Primary or initiating explosives  
5.4.2 Secondary explosives  
5.4.3 Pyrotechnic explosives  
5.4.4 Low explosives  
5.4.5 Commercial explosives – high explosives  
5.4.5.1 Gelatin explosives  
5.4.5.1.1 Dynamites (straight dynamite, ammonia dynamite)  
5.4.5.1.2 Blasting gelatin  
5.4.5.1.3 Semi gelatin  
5.4.5.2 Wet blasting agents  
5.4.5.2.1 Slurry explosives  
5.4.5.2.2 Emulsions  
5.4.5.2.3 Heavy ANFO  
5.4.5.3 Dry blasting agents  
5.4.5.3.1 Explosive ANFO  
5.4.5.3.2 ANFO mixing  
5.4.5.3.3 ANFO loading  
5.4.5.4 Pneumatic loaders and principles of loading  
5.4.5.4.1 Pressure type loaders  
5.4.5.4.2 Ejector type loader  
5.4.5.4.3 Combine type (combining pressure and ejecting features)  
5.4.5.5 Safety aspects  
5.4.5.6 Static hazards associated with ANFO loading  
5.4.5.7 Special types of explosives  
5.4.5.7.1 Permitted explosives  

5 Explosives and blasting  

5.1 Introduction – explosives  
5.2 Detonation and deflagration  
5.3 Common ingredients of explosives  
5.4 Classification of explosives  
5.4.1 Primary or initiating explosives  
5.4.2 Secondary explosives  
5.4.3 Pyrotechnic explosives  
5.4.4 Low explosives  
5.4.5 Commercial explosives – high explosives  
5.4.5.1 Gelatin explosives  
5.4.5.1.1 Dynamites (straight dynamite, ammonia dynamite)  
5.4.5.1.2 Blasting gelatin  
5.4.5.1.3 Semi gelatin  
5.4.5.2 Wet blasting agents  
5.4.5.2.1 Slurry explosives  
5.4.5.2.2 Emulsions  
5.4.5.2.3 Heavy ANFO  
5.4.5.3 Dry blasting agents  
5.4.5.3.1 Explosive ANFO  
5.4.5.3.2 ANFO mixing  
5.4.5.3.3 ANFO loading  
5.4.5.4 Pneumatic loaders and principles of loading  
5.4.5.4.1 Pressure type loaders  
5.4.5.4.2 Ejector type loader  
5.4.5.4.3 Combine type (combining pressure and ejecting features)  
5.4.5.5 Safety aspects  
5.4.5.6 Static hazards associated with ANFO loading  
5.4.5.7 Special types of explosives  
5.4.5.7.1 Permitted explosives
5.4.5.7.2 Seismic explosives 127
5.4.5.7.3 Overbreak control explosives 127
5.4.6 Military explosives 127
5.5 Blasting properties of explosives 128
5.5.1 Strength 128
5.5.2 Detonation velocity 129
5.5.3 Density 131
5.5.4 Water resistance 131
5.5.5 Fume characteristics, or class, or medical aspects 131
5.5.6 Oxygen balance 131
5.5.7 Completion of reaction 133
5.5.8 Detonation pressure 133
5.5.9 Borehole pressure and critical diameter 133
5.5.10 Sensitivity 133
5.5.11 Safety in handling & storage qualities 134
5.5.12 Explosive cost 134
5.6 Explosive initiating devices/systems 134
5.6.1 Detonator system 135
5.6.1.1 Detonators 135
5.6.1.2 Instantaneous detonators 137
5.6.1.2.1 Plain detonator 137
5.6.1.2.2 Instantaneous electric detonators 137
5.6.1.3 Delay detonators 137
5.6.1.3.1 Electric delay detonators 137
5.6.1.3.2 Electronic delay detonators 138
5.6.1.3.3 Non-electric delay detonators: detonating relays (ms connectors) 138
5.6.1.3.4 Primadet and anodet non-electric delay blasting systems 139
5.6.1.3.5 The nonel system 139
5.6.1.3.6 Combine primadet-nonel system 140
5.6.1.3.7 The hercudet blasting cap system 140
5.6.1.3.8 Advantages of short delay blasting 140
5.6.2 Fuse/cord system 141
5.6.2.1 Safety fuse 141
5.6.2.2 Detonating fuse/cord (DC) 141
5.6.2.3 Igniter cords (IC) 141
5.7 Explosive charging techniques 142
5.7.1 Water gel (slurry loader) 143
5.8 Blasting accessories 143
5.8.1 Exploders 143
5.8.2 Circuit testers 144
5.8.3 Other blasting tools 146
5.9 Firing systems – classification 146
5.9.1 While firing with a safety fuse 146
5.9.2 Firing with electric detonators 146
5.9.3 Non-electric systems 146
5.10 Ground blasting techniques 147
  5.10.1 Control/contour blasting 147
    5.10.1.1 Pre-splitting 147
    5.10.1.2 Cushion blasting 148
    5.10.1.3 Smooth blasting & buffer blasting 148
    5.10.1.4 Line drilling 149

5.11 Secondary breaking 149
  5.11.1 Secondary rock breaking methods 150
    5.11.1.1 With the aid of explosives 150
      5.11.1.1.1 Plaster shooting 150
      5.11.1.1.2 Pop shooting 150
      5.11.1.1.3 Releasing jammed muck from the draw points 151
    5.11.2 Without aid of explosives 151
      5.11.2.1 Mechanical rock breaking 151
        5.11.2.1.1 Manual breaking 151
        5.11.2.1.2 Mechanical rock breakers 151
        5.11.2.1.3 Hydraulic rock breakers 151
        5.11.2.1.4 Teledyne rock breaker 152
      5.11.2.2 Electrical rock breaking 153
        5.11.2.2.1 Rock breaking by the use of high frequency current 153
      5.11.2.3 Hydraulic boulder splitter 155

5.12 Use, handling, transportation and storage of explosives 155
  5.12.1 Magazine 156

5.13 Explosive selection 157

5.14 Blasting theory 158
  5.14.1 Adverse impacts of explosives 158
    5.14.1.1 Ground/land vibrations 160
    5.14.1.2 Air blast and noise 162
    5.14.1.3 Rock throw 162

5.15 Drilling and blasting performance 163
  5.15.1 Percentages pull 163
  5.15.2 Over-break factor 163
  5.15.3 Degree of fragmentation 163
  5.15.4 Overall cost 163

5.16 Recent trends in explosives and blasting technology 165

5.17 Concluding remarks 168
  Questions 168
  References 172

6 Mucking, casting and excavation 175

6.1 Introduction 175
6.2 Muck characteristics 176
6.3 Classification 177
6.4 Underground mucking units 177
  6.4.1 Overshot loaders 177
6.4.2  Autoloaders – hopper loaders and LHDs  178
  6.4.2.1  Autoloaders – mucking and delivering  178
  6.4.2.2  Mucking and transporting – load haul and
dump units (LHDs)  181
    6.4.2.2.1  Constructional details  181
    6.4.2.2.2  Special provisions  181
    6.4.2.2.3  Buckets of LHD and other dimensions  181
    6.4.2.2.4  LHD tyres  182
    6.4.2.2.5  Distance, gradient and speed  182
    6.4.2.2.6  Ventilation  182
    6.4.2.2.7  Latest developments  183
  6.4.2.3  Desirable features  183
    6.4.2.3.1  Perfect layout  183
    6.4.2.3.2  Suitable drainage and road
    maintenance  183
    6.4.2.3.3  Well-fragmented muck  184
    6.4.2.3.4  Maintenance  184
    6.4.2.3.5  Trained personnel  184
  6.4.2.4  Advantages  184
  6.4.2.5  Limitations  185
  6.4.2.6  Manufacturers  185

6.5  Arm loaders  186
  6.5.1  Gathering-arm-loader (GAL)  186
  6.5.2  Arm loaders for sinking operations  186
  6.5.3  Riddle mucker  186
  6.5.4  Cryderman mucker  186
  6.5.5  Cactus-grab muckers  186
  6.5.6  Backhoe mucker  187

6.6  Scrapers  187

6.7  Mucking in tunnels  187
  6.7.1  Dipper and hydraulic shovels  188
  6.7.2  Mucking in TBM driven tunnels  188

6.8  Surface – excavation, loading and casting units  188

6.9  Wheel loaders – front end loaders  189

6.10  Backhoe  190

6.11  Hydraulic excavators  190

6.12  Shovel  191

6.13  Dragline  192
    6.13.1  Multi bucket excavators  195

6.14  Bucket chain excavator (BCE)  195

6.15  Bucket wheel excavator (BWE)  195

6.16  Calculations for selection of shovel/excavator  198

6.17  Total cost calculations  200

6.18  Governing factors for the selection of mucking equipment  200

6.19  The way forward  201
    Questions  202
    References  204
7 Transportation – haulage and hoisting

7.1 Introduction 205

7.2 Haulage system 205
- 7.2.1 Rail or track mounted – rope haulage 206
  - 7.2.1.1 Rope haulage calculations 208
  - 7.2.1.1.1 Direct rope haulage system 208
  - 7.2.1.1.2 Endless rope haulage system 209
  - 7.2.1.2 Scope and applications of rope haulage 209
- 7.2.2 Locomotive haulage 209
  - 7.2.2.1 Electric locomotives 210
  - 7.2.2.2 Battery locomotives 211
  - 7.2.2.3 Combination locomotives 211
  - 7.2.2.4 Diesel locomotives 211
  - 7.2.2.5 Compressed air locomotives 212
  - 7.2.2.6 Other fittings 213
  - 7.2.2.7 Locomotive calculations 213
- 7.2.3 Trackless or tyred haulage system 214
  - 7.3.1 Automobiles 214
  - 7.3.2 LHD 214
  - 7.3.3 Shuttle car 215
  - 7.3.4 Underground trucks 215
    - 7.3.4.1 Trackless or tyred haulage system 217
- 7.4 Conveyor system 221
  - 7.4.1 Belt conveyors 221
    - 7.4.1.1 Conveyor calculations 223
  - 7.4.2 Cable belt conveyors 224
  - 7.4.3 Scraper chain conveyors 224
- 7.5 Hoisting or winding system 225
  - 7.5.1 Head-frame or head-gear 226
  - 7.5.2 Shaft conveyances 226
  - 7.5.3 Rope equipment 226
  - 7.5.4 Classification of hoisting system 228
    - 7.5.4.1 Multi-rope friction winding system 229
  - 7.5.5 Hoisting cycle 231
  - 7.5.6 Calculations of suspended load during hoisting 231
  - 7.5.7 Use of safety devices with a hoisting system 234
- 7.6 Aerial ropeway 234
  - 7.6.1 Aerial ropeway calculations 235
- 7.7 Ropes 236
  - 7.7.1 Rope calculations 239
- 7.8 Track and mine car 240
  - 7.8.1 Track 240
  - 7.8.2 Mine cars 240
- 7.9 The way forward 241
  Questions 242
  References 247
8 Supports

8.1 Introduction – necessity of supports 249
8.2 Classification of supports 250
8.3 Self support by in-place (in-situ) rock 250
  8.3.1 Support by the use of natural pillars 250
  8.3.2 Use of artificial supports 252
    8.3.2.1 Brick and stone masonry 252
    8.3.2.2 Wooden (timber) supports 252
      8.3.2.2.1 Calculations with regard to wooden supports 253
    8.3.2.3 Steel supports 256
      8.3.2.3.1 Steel props, powered and shield supports 257
      8.3.2.3.2 Rock bolting 259
    8.3.2.4 Concrete supports 265
    8.3.2.5 Support by filling 268
8.4 Selection of support 270
  8.4.1 Measures to preserve the stability of the stoped out workings or to minimize problems of ground stability 270
8.5 Effect of ore extraction upon displacement of country rock and surface 271
8.6 The way forward 272
Questions 272
References 274

9 Drives and tunnels (conventional methods) 277

9.1 Introduction – function of drives and tunnels 277
9.2 Drivage techniques (for drives and tunnels) 277
9.3 Drivage techniques with the aid of explosives 278
  9.3.1 Pattern of holes 278
    9.3.1.1 Mechanized-cut kerf 279
    9.3.1.2 Blasting off the solid 279
      9.3.1.2.1 Parallel hole cuts 279
      9.3.1.2.2 Verification of pattern of holes 291
    9.3.2 Charging and blasting the rounds 292
      9.3.2.1 Placement of primer 292
      9.3.2.2 Stemming 292
      9.3.2.3 Depth of round/hole 292
      9.3.2.4 Charge density in cut-holes and rest of the face area 292
    9.3.3 Smooth blasting 293
      9.3.3.1 Charging and blasting procedure 294
      9.3.3.2 Use of ANFO in drives and tunnels 295
9.4 Muck disposal and handling (mucking and transportation) 295
9.5 Ventilation 298
  9.5.1 Mine opening ventilation 299
    9.5.1.1 Using general air flow 299
    9.5.1.2 Using auxiliary fans: forcing, exhaust or contra rotating 299
  9.5.2 Ventilation during civil tunneling 301
9.6 Working cycle (including auxiliary operations) 302
9.7 Driving large sized drives/tunnels in tough rocks 303
9.7.1 Full-face driving/tunneling 303
9.7.2 Pilot heading technique 304
9.7.3 Heading and bench method 305
9.8 Conventional tunneling methods: tunneling through the soft ground and soft rocks 305
9.9 Supports for tunnels and mine openings 307
9.9.1 Classification 308
9.9.2 Selection of supports 311
9.10 Driving without aid of explosives 314
9.11 Pre-cursor or prior to driving civil tunnels 315
9.11.1 Site investigations 315
9.11.2 Location of tunnels 315
9.11.3 Rocks and ground characterization 315
9.11.4 Size, shape, length and orientation (route) of tunnels 317
9.11.5 Preparatory work required 317
9.12 Past, present and future of tunneling technology 317
9.13 Over-break and scaling – some innovations 319
9.14 Longer rounds – some trials 319
9.15 The way forward 322
Questions 323
References 325

10 Tunneling by roadheaders and impact hammers 327
10.1 Tunneling by boom-mounted roadheaders 327
10.2 Classification boom-mounted roadheaders 330
10.2.1 Ripper (transverse) type roadheaders – (Cutter heads with rotation perpendicular to the boom axis) 330
10.2.1.1 Bar type 331
10.2.1.2 Disc type 331
10.3 Milling or longitudinal (auger) roadheaders 331
10.3.1 Borer type roadheaders 332
10.4 Classification based on weight 333
10.5 Advantages of roadheaders 333
10.6 Important developments 333
10.7 Procedure of driving by the heading machines 335
10.8 Auxiliary operations 336
10.8.1 Ground support 336
10.9 Hydraulic impact hammer tunneling 336
10.10 Excavation procedure and cycle of operations 336
10.10.1 Hammer’s working cycle 337
10.11 Merit and limitations 338
10.12 Partial face rotary rock tunneling machines 338
10.13 Excavators 339
10.13.1 Excavators mounted within shield 339
10.13.1.1 Excavator buckets 339
10.14 Excavator with multiple tool miner (MTM) attachments
10.14.1 Excavator mounted within a shield
10.14.2 Excavator-mounted cutter booms (Partial face machines for NATM)

10.15 The way forward
Questions
References

11 Full-face tunnel borers (TBMs) & special methods

11.1 Introduction
11.1.1 Improved understanding

11.2 Tunneling methods and procedures

11.3 Full-face tunneling machines
11.3.1 Full-face tunnel borers (mechanical) TBM – open and shielded
11.3.2 Mechanical excavation of the full cross-section with open type machines
11.3.2.1 Open main beam machines
11.3.2.2 Single shield
11.3.2.3 Double shield
11.3.2.4 Enlarging TBM

11.4 Mini tunnel borers

11.5 Boring system

11.6 Rock cutting tools and their types
11.6.1 Cutting head configuration

11.7 TBM performance
11.7.1 Economical aspects

11.8 Size of unit and its overall length including its trailing gear
11.8.1 Advantages
11.8.2 Disadvantages

11.9 Backup system/activities
11.9.1 Muck disposal
11.9.2 Single track
11.9.3 Double track
11.9.4 Continuous conveyor system
11.9.5 Other back-ups include

11.10 TBMs for soft ground/ formations
11.10.1 Full-face shield with picks
11.10.2 Compressed air shields
11.10.3 Slurry shield
11.10.4 Earth pressure balance
11.10.4.1 Segments
11.10.4.2 Back filling
11.10.4.3 Auxiliary construction measures
11.10.5 Developments

11.11 Phases of tunneling project
11.11.1 Tunnel portal
11.11.2 Phases of a TBM project
### 11.12 Future technology
- 11.12.1 Hard rock TBMs
- 11.12.2 Soft ground machines

### 11.13 New Austrian tunneling method (NATM)
- 11.13.1 NATM design philosophy and typical features
- 11.13.2 Ground categories and tunneling procedures
  - 11.13.2.1 Excavation sequence
- 11.13.3 Semi-mechanized methods

### 11.14 Tunneling through abnormal or difficult ground using special methods
- 11.14.1 Ground treatment
  - 11.14.1.1 Reinforcement
  - 11.14.1.2 Treatment that tackles the problems arising due to the presence of water
  - 11.14.1.3 Lowering water table/ground water
  - 11.14.1.4 Use of compressed air to hold back water
  - 11.14.1.5 Grouting
  - 11.14.1.6 Freezing

### 11.15 Cut and cover method of tunneling

### 11.16 Submerged tubes/tunnels

### 11.17 The way forward

### Questions

### References

### 12 Planning

#### 12.1 Economic studies
- 12.1.1 Phases or stages in economic studies
  - 12.1.1.1 Preliminary studies or valuation
  - 12.1.1.2 Intermediate economic study or pre-feasibility study
  - 12.1.1.3 Feasibility study
    - 12.1.1.3.1 Information on deposit
    - 12.1.1.3.2 Information on general project economics
    - 12.1.1.3.3 Mining method selection
    - 12.1.1.3.4 Processing methods
    - 12.1.1.3.5 Ecology
    - 12.1.1.3.6 Capital and operating costs estimates
    - 12.1.1.3.7 Project cost & rates of return
    - 12.1.1.3.8 Comments
- 12.1.2 Conceptual mine planning and detailed project reports
  - 12.1.2.1 Conceptual studies/models
  - 12.1.2.2 Engineering studies
  - 12.1.2.3 Models and detailed design

#### 12.2 Mine design elements
- 12.2.1 Mineral resources and reserves
- 12.2.2 Cutoff grade
12.2.2.1 Mining & process plant input-output calculations (for a copper mining complex) 405
12.2.2.2 Cutoff grade calculations 406
12.2.3 Interrelationship amongst the mine design elements 406
12.2.4 Mine life 407
12.2.4.1 Phases or stages during mine life 408
12.3 Dividing property for the purpose of underground mining 409
12.3.1 Panel system 411
12.3.2 Level system 411
12.3.3 Level interval 412
12.4 Mine planning duration 413
12.5 Mine development – introduction 414
12.6 Access to deposit or means of mine access 415
12.7 System – opening up a deposit 417
12.7.1 Opening deposit in parts 417
12.7.2 Opening up the whole deposit 417
12.8 Positioning and developing the main haulage levels 420
12.8.1 Selecting development in ore or rock (country rock) 420
12.8.2 Vertical development in the form of raises 423
12.8.3 Connecting main levels by ramps/declines/slopes 424
12.8.4 Determination of optimal load concentration point 424
12.8.4.1 Analytical method 424
12.8.4.2 Graphical method: funicular diagram 425
12.9 Size and shape of mine openings and tunnels 426
12.10 Pit top layouts 428
12.11 Pit bottom layouts 428
12.11.1 Types of pit bottom layouts 429
12.12 Structures concerning pit bottom layouts 431
12.13 The way forward 431
Questions 432
References 437

13 Excavations in upward direction – raising 439
13.1 Introduction 439
13.2 Raise applications in civil and construction industries 439
13.3 Classification – types of raises for mines 440
13.4 Raise driving techniques 441
13.5 Conventional raising method: open raising 441
13.6 Conventional raising method: raising by compartment 442
13.7 Raising by the use of mechanical climbers: Jora hoist 443
13.8 Raising by mechanical climbers: Alimak raise climber 443
13.8.1 Preparatory work and fittings 447
13.8.2 Ignition and telephone systems 447
13.8.3 Cycle of operations 447
13.8.4 Performance 448
13.8.5 Design variants 448
13.8.6 Air-driven unit 448
13.8.7 Electrically driven unit 448
13.8.8 Diesel-hydraulic unit 449
13.9 Blasthole raising method: long-hole raising 449
  13.9.1 Marking the raise 449
  13.9.2 Equipment installation 449
  13.9.3 Drilling 450
  13.9.4 Raise correlation 450
  13.9.5 Blowing and plugging the holes 450
  13.9.6 Charging and blasting 451
  13.9.7 Limitations 452
  13.9.8 Advantages 452
13.10 Blasthole raising method: drop raising 453
13.11 Raising by the application of raise borers 456
13.12 Raise boring in a package – BorPak 459
13.13 Ore pass/waste rock pass 459
  13.13.1 Size and shape 460
  13.13.2 Ore pass lining 461
  13.13.3 Design consideration of rock pass/ore pass 461
13.14 The way forward 464
  Questions 465
  References 466

14 Shaft sinking 469
14.1 Introduction 469
14.2 Location 469
14.3 Preparatory work required 470
14.4 Sinking appliances, equipment and services 470
14.5 Sinking methods and procedure 472
14.6 Reaching up to the rock head 472
  14.6.1 Pre-sink 473
14.7 Sinking through the rock 474
  14.7.1 Drilling 475
  14.7.2 Blasting 477
  14.7.3 Lashing and mucking 478
  14.7.4 Hoisting 478
  14.7.5 Support or shaft lining 480
  14.7.6 Auxiliary operations 480
    14.7.6.1 Dewatering 480
    14.7.6.2 Ventilation 480
    14.7.6.3 Illumination 482
    14.7.6.4 Shaft centering 482
    14.7.6.5 Station construction and initial development 482
14.8 Special methods of shaft sinking 483
14.9 Piling system 484
14.10 Caisson method 484
  14.10.1 Sinking drum process 484
  14.10.2 Forced drop-shaft method 486
14.10.3 Pneumatic caisson method 486
14.11 Special methods by temporary or permanent isolation of water 487
  14.11.1 Cementation 487
    14.11.1.1 Boring/Drilling 487
    14.11.1.2 Cementation 487
    14.11.1.3 Sinking and walling 488
14.12 The freezing process 488
  14.12.1 Drilling and lining of boreholes 489
  14.12.2 Formation and maintenance of the ice column 490
  14.12.3 Actual sinking operations 491
  14.12.4 Thawing of ice wall 491
  14.12.5 Freezing – shafts 492
  14.12.6 Ground freezing practices in Germany 492
14.13 Shaft drilling and boring 495
  14.13.1 Shaft drilling 495
  14.13.2 Shaft boring 495
14.14 Safety in sinking shafts 497
  14.14.1 Field tests and measurements 497
14.15 The way forward 499
  Questions 500
  References 501

15 Large sub-surface excavations 503
15.1 Introduction 503
15.2 Caverns 503
  15.2.1 Constructional details – important aspects 505
    15.2.1.1 Construction procedure 506
  15.3 powerhouse caverns 508
  15.4 Oil storage caverns 508
  15.5 Repository 509
  15.6 Salt cavern storage 512
  15.7 Aquifer storage 513
  15.8 Exhibition hall caverns 514
15.9 Underground chambers in mines 516
15.10 Equipment and services selection 517
15.11 The way forward 522
  Questions 523
  References 524

16 Underground mining/stoping methods & mine closure 527
16.1 Introduction 527
  16.1.1 Factors governing choice of a mining method 527
    16.1.1.1 Shape and size of the deposit 527
    16.1.1.2 Thickness of deposit 528
    16.1.1.3 Dip of the deposit 529
    16.1.1.4 Physical and mechanical characteristics of the ore and the enclosing rocks 529
16.1.1.5 Presence of geological disturbances and influence of the direction of cleats or partings 532
16.1.1.6 Degree of mechanization and output required 532
16.1.1.7 Ore grade and its distribution, and value of the product 534
16.1.1.8 Depth of the deposit 534
16.1.1.9 Presence of water 535
16.1.1.10 Presence of gases 535
16.1.1.11 Ore & country rock susceptibility to caking and oxidation 535

16.1.2 Desirable features of selecting a stoping method 536
16.1.3 Classification - stoping methods 538

16.2 Open stoping methods 540
16.2.1 Open stoping method - room & pillar stoping 540
   16.2.1.1 Introduction 540
   16.2.1.2 Stope preparation 540
   16.2.1.3 Unit operations 541
   16.2.1.4 Stoping operations 544
   16.2.1.5 Bord and pillar 545
   16.2.1.6 Block system 546
   16.2.1.7 Stope and pillar
      16.2.1.7.1 Advantages 549
      16.2.1.7.2 Limitations 549

16.2.2 Open stoping method - shrinkage stoping 549
   16.2.2.1 Introduction 549
   16.2.2.2 Stope preparation 551
   16.2.2.3 Unit operations 551
   16.2.2.4 Stoping operations 552
   16.2.2.5 Layouts
      16.2.2.5.1 Winning the pillars 552
      16.2.2.5.2 Advantages 552
      16.2.2.5.3 Limitations 553

16.2.3 Open stoping method - sublevel stoping 553
   16.2.3.1 Introduction 553
   16.2.3.2 Sublevel stoping with benching 554
   16.2.3.3 Blasthole stoping 554
   16.2.3.4 Longitudinal sublevel stoping 554
   16.2.3.5 Transverse sublevel stoping 556
   16.2.3.6 Blasthole drilling 556

16.2.4 Large blasthole stoping 558
   16.2.4.1 Stope preparation (general procedure) 558
   16.2.4.2 VCR method 562
   16.2.4.3 Unit operations 562
   16.2.4.4 Layouts
      16.2.4.4.1 Advantages 564
      16.2.4.4.2 Limitations 564
      16.2.4.4.3 Winning the pillars 564
16.3 Supported stoping methods

16.3.1 Supported stoping method – stull stoping

16.3.1.1 Introduction
16.3.1.2 Unit operations
16.3.1.3 Auxiliary operations
16.3.1.4 Stoping preparation
16.3.1.5 Stoping
16.3.1.6 Layouts

16.3.1.6.1 Variants
16.3.1.6.2 Advantages
16.3.1.6.3 Limitations

16.3.2 Supported stoping method: cut & fill stoping

16.3.2.1 Introduction
16.3.2.2 Stoping preparation
16.3.2.3 Stoping
16.3.2.4 Unit operations
16.3.2.5 Auxiliary operations

16.3.2.5.1 Advantages
16.3.2.5.2 Limitations
16.3.2.5.3 Variants

16.3.2.6 Cut and fill with flat back
16.3.2.7 Cut and fill with inclined slicing
16.3.2.8 Post and pillar cut and fill stoping
16.3.2.9 Stop drive or undercut and fill stoping

16.3.2.9.1 Filling methods during deep mining
16.3.2.9.2 Top slicing (An undercut-and-fill method)

16.3.2.9.3 Filling materials

16.3.3 Supported stoping method – square set stoping

16.3.3.1 Introduction
16.3.3.2 Stoping preparation
16.3.3.3 Stoping
16.3.3.4 Unit operations
16.3.3.5 Auxiliary operations
16.3.3.6 Layouts

16.3.3.6.1 Advantages
16.3.3.6.2 Limitations

16.4 Caving methods

16.4.1 Caving method – longwall mining

16.4.1.1 Introduction
16.4.1.2 Unit operations
16.4.1.3 While mining coal
16.4.1.4 Stoping preparation
16.4.1.5 Stoping operations
16.4.1.6 Layouts

16.4.1.6.1 Advantages
16.4.1.6.2 Limitations

16.4.1.7 Mining at ultra depths
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.4.2</td>
<td>Caving method – sublevel caving</td>
<td>594</td>
</tr>
<tr>
<td>16.4.2.1</td>
<td>Introduction</td>
<td>594</td>
</tr>
<tr>
<td>16.4.2.2</td>
<td>Unit operations</td>
<td>596</td>
</tr>
<tr>
<td>16.4.2.2.1</td>
<td>Variants</td>
<td>596</td>
</tr>
<tr>
<td>16.4.2.3</td>
<td>Stope preparation (transverse sublevel caving)</td>
<td>596</td>
</tr>
<tr>
<td>16.4.2.4</td>
<td>Stope preparation (sublevel caving - longitudinal)</td>
<td>598</td>
</tr>
<tr>
<td>16.4.2.5</td>
<td>Layouts</td>
<td>598</td>
</tr>
<tr>
<td>16.4.2.5.1</td>
<td>Advantages</td>
<td>598</td>
</tr>
<tr>
<td>16.4.2.5.2</td>
<td>Limitations</td>
<td>599</td>
</tr>
<tr>
<td>16.4.3</td>
<td>Caving method – block caving</td>
<td>600</td>
</tr>
<tr>
<td>16.4.3.1</td>
<td>Introduction</td>
<td>600</td>
</tr>
<tr>
<td>16.4.3.2</td>
<td>Unit operations</td>
<td>601</td>
</tr>
<tr>
<td>16.4.3.2.1</td>
<td>Variants</td>
<td>602</td>
</tr>
<tr>
<td>16.4.3.3</td>
<td>Methods of draw</td>
<td>604</td>
</tr>
<tr>
<td>16.4.3.4</td>
<td>Stope preparation</td>
<td>605</td>
</tr>
<tr>
<td>16.4.3.5</td>
<td>Layouts</td>
<td>606</td>
</tr>
<tr>
<td>16.4.3.5.1</td>
<td>Advantages</td>
<td>612</td>
</tr>
<tr>
<td>16.4.3.5.2</td>
<td>Limitations</td>
<td>612</td>
</tr>
<tr>
<td>16.5</td>
<td>Common aspects</td>
<td>613</td>
</tr>
<tr>
<td>16.5.1</td>
<td>Stope design</td>
<td>616</td>
</tr>
<tr>
<td>16.5.1.1</td>
<td>Model parameters</td>
<td>616</td>
</tr>
<tr>
<td>16.5.1.2</td>
<td>Design parameters</td>
<td>617</td>
</tr>
<tr>
<td>16.5.2</td>
<td>Application of computers in stope design and economic analysis</td>
<td>620</td>
</tr>
<tr>
<td>16.5.3</td>
<td>Proposed methodology for selection of a stoping method for the base metal deposits with a case study</td>
<td>620</td>
</tr>
<tr>
<td>16.6</td>
<td>Mine liquidation</td>
<td>633</td>
</tr>
<tr>
<td>16.6.1</td>
<td>Liquidation of the stopes of different types</td>
<td>633</td>
</tr>
<tr>
<td>16.6.2</td>
<td>Planning liquidation</td>
<td>634</td>
</tr>
<tr>
<td>16.6.3</td>
<td>Liquidation techniques</td>
<td>634</td>
</tr>
<tr>
<td>16.6.4</td>
<td>Pillar types &amp; methods of their extraction</td>
<td>635</td>
</tr>
<tr>
<td>16.6.4.1</td>
<td>Pillar extraction methods</td>
<td>636</td>
</tr>
<tr>
<td>16.6.4.2</td>
<td>Planning a heavy-blast for liquidation purpose</td>
<td>637</td>
</tr>
<tr>
<td>16.6.5</td>
<td>Case studies</td>
<td>637</td>
</tr>
<tr>
<td>16.6.5.1</td>
<td>Heavy blasting at a copper mine</td>
<td>637</td>
</tr>
<tr>
<td>16.6.5.2</td>
<td>Remnant pillars' blast at lead-zinc mine</td>
<td>642</td>
</tr>
<tr>
<td>16.6.5.2.1</td>
<td>Blast planning</td>
<td>642</td>
</tr>
<tr>
<td>16.6.5.2.2</td>
<td>Results of the blast</td>
<td>643</td>
</tr>
<tr>
<td>16.7</td>
<td>Planning for mine closure</td>
<td>646</td>
</tr>
<tr>
<td>16.7.1</td>
<td>Introduction</td>
<td>646</td>
</tr>
<tr>
<td>16.7.2</td>
<td>Phases – mine closure</td>
<td>646</td>
</tr>
<tr>
<td>16.7.3</td>
<td>The integrated mine closure planning guidelines (toolkit)</td>
<td>646</td>
</tr>
<tr>
<td>16.7.3.1</td>
<td>Salient features (parameters to be considered) for closure planning</td>
<td>648</td>
</tr>
<tr>
<td>16.7.3.2</td>
<td>Guidelines/toolkit details</td>
<td>652</td>
</tr>
<tr>
<td>16.7.3.3</td>
<td>Glossary</td>
<td>668</td>
</tr>
<tr>
<td>16.8</td>
<td>The way forward</td>
<td>671</td>
</tr>
<tr>
<td></td>
<td>Questions</td>
<td>671</td>
</tr>
<tr>
<td></td>
<td>References</td>
<td>681</td>
</tr>
</tbody>
</table>
17 Surface excavations 685

17.1 Introduction – surface mining methods 685

17.2 Open pit mining 685
  17.2.1 Open pit elements 686
    17.2.1.1 Bench angle or slope 688
  17.2.2 Overall pit slope angle 688
    17.2.2.1 Computation of overall pit slope angle 688
  17.2.3 Stripping ratio 691
  17.2.4 Overall pit profile 693
    17.2.4.1 Coning concept for open pit design 693
  17.2.5 Stripping sequence 694

17.3 Haul roads 695

17.4 Ramp and its gradient 695

17.5 Open cast mining/strip mining 697
  17.5.1 Introduction 697
  17.5.2 Design aspects 697
  17.5.3 Operational details – surface mines 698
    17.5.3.1 Planning 699
    17.5.3.2 Site preparation 699
    17.5.3.3 Opening up the deposit 699
  17.5.4 Development 701
    17.5.4.1 Waste rock dumps 701
  17.5.5 Bench blasting design patterns 701
    17.5.5.1 Linear formulas 702
    17.5.5.2 Power formulas derived by statistical analysis 704
    17.5.5.3 Formulas related to energy transfer in rock blasting, burden and blasthole diameter 704
    17.5.5.4 Tatiya and Adel's formula to determine burden with respect to blasthole diameter 705
    17.5.5.5 Powder factor method 705
  17.5.6 Drilling and blasting operations 706
  17.5.7 Cast blasting 709
  17.5.8 Muck handling 710
  17.5.9 Selection of excavator and transportation units 710
  17.5.10 Calculations for selection of shovel/excavator 710
    17.5.10.1 Time factor 710
    17.5.10.2 Operational factor (O_t) 710
    17.5.10.3 Bucket fill factor (B_f) 711
  17.5.11 Theoretical output from an excavator/hr 714
  17.5.12 Output from a continuous flow unit 715
  17.5.13 Transportation schemes 715
  17.5.14 In-pit crushing and conveying 715
  17.5.15 Dumping site 716
  17.5.16 Integrated or matching equipment complex 719
    17.5.16.1 Global Positioning System (GPS) 720
  17.5.17 Quarrying of dimension stones 720

17.6 Quarrying of dimension stones 721
### Contents

17.6.1 Drilling 721  
17.6.2 Line drilling 726  
17.6.3 Discontinuous or spaced drilling 727  
17.6.4 Drilling and blasting 727  
17.6.4.1 Blast results at Vanga granite quarry in southern Sweden 730  
17.6.5 Wire cutter – helicoid and diamond 731  
17.6.6 Cutter saw and rock channellers (impact cutting machines) 734  
17.6.6.1 Merits 735  
17.6.6.2 Disadvantages 735  
17.7 The diamond belt saw 735  
17.7.1 Water jet technology 736  
17.7.2 Thermal cutting 737  
17.7.3 Underground quarrying 738  
17.8 Earth movers 738  
17.9 The way forward 745  
Questions 745  
References 751

### 18 Hazards, occupational health and safety (OHS), environment and loss prevention 753

18.1 Introduction 753  
18.2 Potential excavation hazards 754  
18.2.1 Hazards (risks) analysis and management 757  
18.3 Safety and accidents 758  
18.3.1 Terminology 758  
18.3.2 Safety strategies 759  
18.3.3 Safety elements 760  
18.3.3.1 People/mine workers 760  
18.3.3.2 The systems 768  
18.3.3.3 The working environment (conditions) 770  
18.3.4 Accidents 771  
18.3.4.1 Accidents/incident analysis & calculations 771  
18.3.4.2 Common accident areas/heads 773  
18.3.4.3 Accident costs 774  
18.3.4.4 Remedial measures 774  
18.3.4.5 Measures/preparedness 774  
18.3.4.6 Hazards analysis methods 774  
18.4 Occupational health and surveillance 778  
18.4.1 Industrial hygiene 778  
18.4.1.1 Aqueous effluents – permissible quality & efficient discharge 778  
18.4.1.2 House keeping 779  
18.4.1.3 The 5S concept 779  
18.4.2 Working conditions 780
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.4.3</td>
<td>Ergonomics</td>
<td>781</td>
</tr>
<tr>
<td>18.4.3.1</td>
<td>Introduction</td>
<td>781</td>
</tr>
<tr>
<td>18.4.3.2</td>
<td>Impacts of poor ergonomics</td>
<td>781</td>
</tr>
<tr>
<td>18.4.4</td>
<td>Occupational health surveillance</td>
<td>782</td>
</tr>
<tr>
<td>18.4.4.1</td>
<td>Organizational culture and workplace stresses</td>
<td>783</td>
</tr>
<tr>
<td>18.4.4.2</td>
<td>'Presenteeism' – lost performance at work</td>
<td>784</td>
</tr>
<tr>
<td>18.4.4.3</td>
<td>Periodic health surveillance: based on exposure-risk</td>
<td>784</td>
</tr>
<tr>
<td>18.4.4.4</td>
<td>Notified diseases and preventive measures</td>
<td>785</td>
</tr>
<tr>
<td>18.5</td>
<td>Environment degradation and mitigation measures</td>
<td>786</td>
</tr>
<tr>
<td>18.5.1</td>
<td>Balance system/equation</td>
<td>787</td>
</tr>
<tr>
<td>18.5.2</td>
<td>Environmental degradation</td>
<td>787</td>
</tr>
<tr>
<td>18.5.3</td>
<td>Environmental management</td>
<td>788</td>
</tr>
<tr>
<td>18.5.4</td>
<td>Environmental system</td>
<td>788</td>
</tr>
<tr>
<td>18.6</td>
<td>Loss prevention</td>
<td>788</td>
</tr>
<tr>
<td>18.6.1</td>
<td>Classification – losses</td>
<td>788</td>
</tr>
<tr>
<td>18.6.2</td>
<td>Abnormalities</td>
<td>791</td>
</tr>
<tr>
<td>18.6.3</td>
<td>5W-2H analysis</td>
<td>793</td>
</tr>
<tr>
<td>18.6.4</td>
<td>Wastage</td>
<td>798</td>
</tr>
<tr>
<td>18.6.5</td>
<td>Case-study illustrating computation of financial losses</td>
<td>799</td>
</tr>
<tr>
<td>18.6.6</td>
<td>Use of Information Technology (IT) in integrating processes and information</td>
<td>800</td>
</tr>
<tr>
<td>18.7</td>
<td>The way forward</td>
<td>801</td>
</tr>
<tr>
<td></td>
<td>Questions</td>
<td>802</td>
</tr>
<tr>
<td></td>
<td>References</td>
<td>805</td>
</tr>
</tbody>
</table>

19  **Sustainable Development**  

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.1</td>
<td>Sustainable Development (SD) in mining</td>
<td>807</td>
</tr>
<tr>
<td>19.1.1</td>
<td>Sustainable development</td>
<td>807</td>
</tr>
<tr>
<td>19.1.2</td>
<td>Global issues &amp; backlog on sustainable development</td>
<td>807</td>
</tr>
<tr>
<td>19.1.3</td>
<td>Sustainable development in mining</td>
<td>807</td>
</tr>
<tr>
<td>19.2</td>
<td>Stakeholders and sustainable development</td>
<td>809</td>
</tr>
<tr>
<td>19.2.1</td>
<td>Principles/guidelines for SD by ICMM</td>
<td>809</td>
</tr>
<tr>
<td>19.2.2</td>
<td>Status of SD in mining, based on stakeholders' views though a survey by globalscan</td>
<td>811</td>
</tr>
<tr>
<td>19.3</td>
<td>Scenarios influencing mining industry</td>
<td>813</td>
</tr>
<tr>
<td>19.3.1</td>
<td>Population growth and resulting impacts/implications</td>
<td>813</td>
</tr>
<tr>
<td>19.3.2</td>
<td>Use of minerals by world’s citizens</td>
<td>813</td>
</tr>
<tr>
<td>19.3.3</td>
<td>Mineral consumption trends</td>
<td>815</td>
</tr>
<tr>
<td>19.3.4</td>
<td>Status of quality, quantity, type of mineral and <em>resources</em> depletion</td>
<td>815</td>
</tr>
<tr>
<td>19.3.5</td>
<td>Mineral consumption prediction</td>
<td>817</td>
</tr>
<tr>
<td>19.3.6</td>
<td>Mining industry’s inherent problems and challenges</td>
<td>818</td>
</tr>
<tr>
<td>19.3.7</td>
<td>Global risk ranking and competitiveness in the mining sector</td>
<td>819</td>
</tr>
<tr>
<td>19.4</td>
<td>Is mining industry equipped to meet the challenges?</td>
<td>819</td>
</tr>
<tr>
<td>19.4.1</td>
<td>Technological developments in mining</td>
<td>819</td>
</tr>
<tr>
<td>19.4.2</td>
<td>Initiatives already taken globally to meet demand of minerals mass consumption</td>
<td>821</td>
</tr>
</tbody>
</table>
19.5 Proposed strategy to run mines is an economically viable (beneficial) way
   19.5.1 Exploration: huge, intensive & speedy together with bringing precision in ore evaluation techniques
   19.5.2 Establishing mineral inventory, cutoff grade and ore reserves
   19.5.3 Division of mineral property (i.e. orebody or coal deposits into level and panels)
   19.5.4 Locale-specific challenges and proposed solutions/way-outs
      19.5.4.1 Underground metalliferous mining challenges
      19.5.4.2 Underground coal mining challenges
      19.5.4.3 Open cast/open pit mines (coal & non coal) challenges
   19.5.5 Mining difficult deposits using non-conventional technologies
   19.5.6 Improved fragmentation – a better way to extract minerals (ore, waste rocks, overburden) to save energy
   19.5.7 Precision in operations – maximizing recovery
   19.5.8 The critical path to full automation
   19.5.9 Effective utilization of resources through standardization & benchmarking
   19.5.10 Needs-based changes, research and development

19.6 Measures for SD through improvements environmentally, socially and ethically
   19.6.1 HSE – a critical business activity for sustainable development
   19.6.2 Economic development regional as well as local – A case-study

19.7 Legal compliances and mining policy
   19.7.1 Mining laws – legislation
   19.7.2 Minerals & mining policy

19.8 Quality of human resources
   19.8.1 Academic (educational) status and standard of mining schools

19.9 The ultimate aim
   19.9.1 Contented employees & stakeholders
   19.9.2 Efficient systems including best practices
   19.9.3 Legal compliance including Environment Management Systems (EMS)
   19.9.4 World Class Management (WCM)

19.10 The way forward: proposed milestones/strategy
   Questions
   References

Subject index