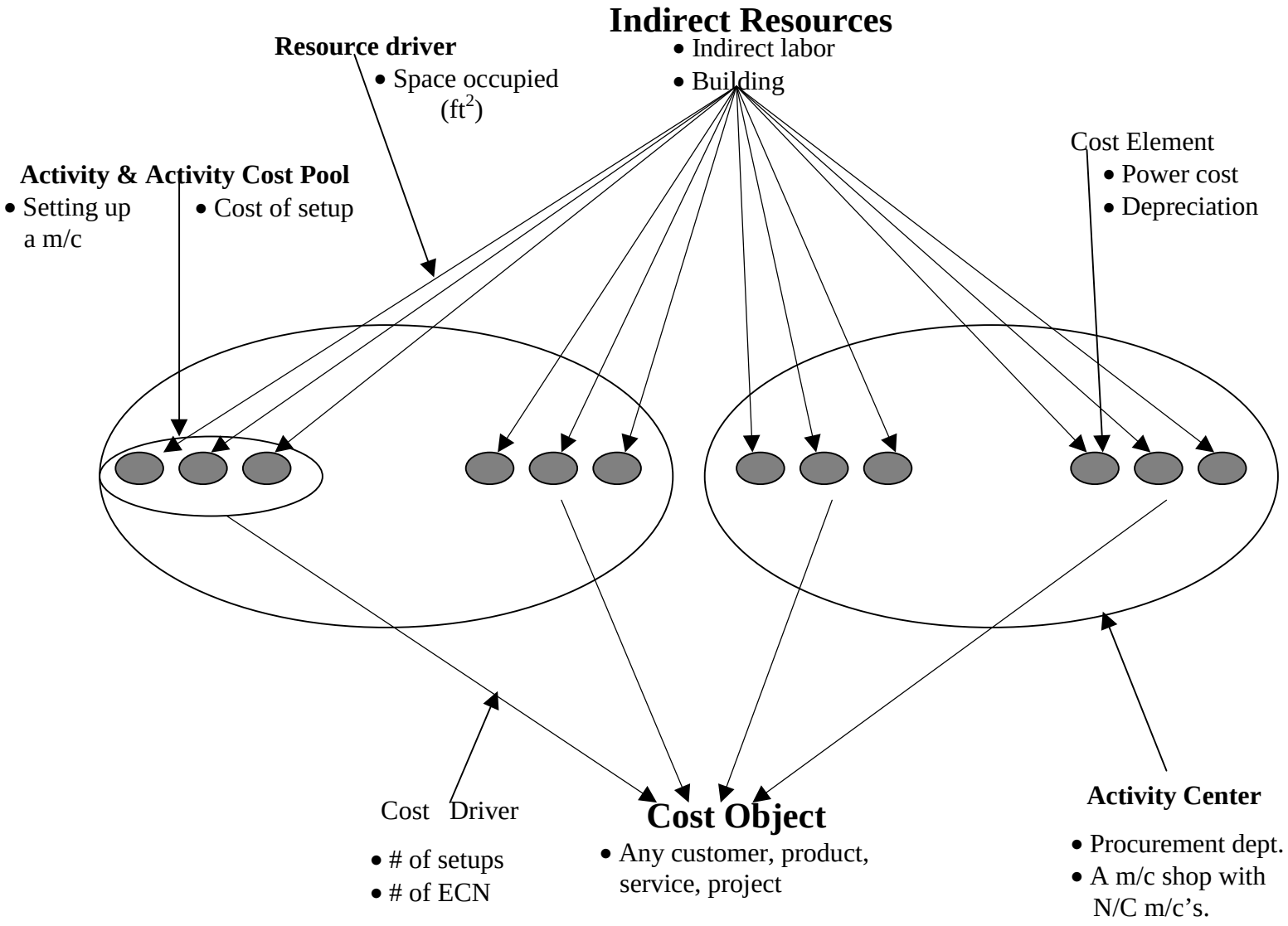
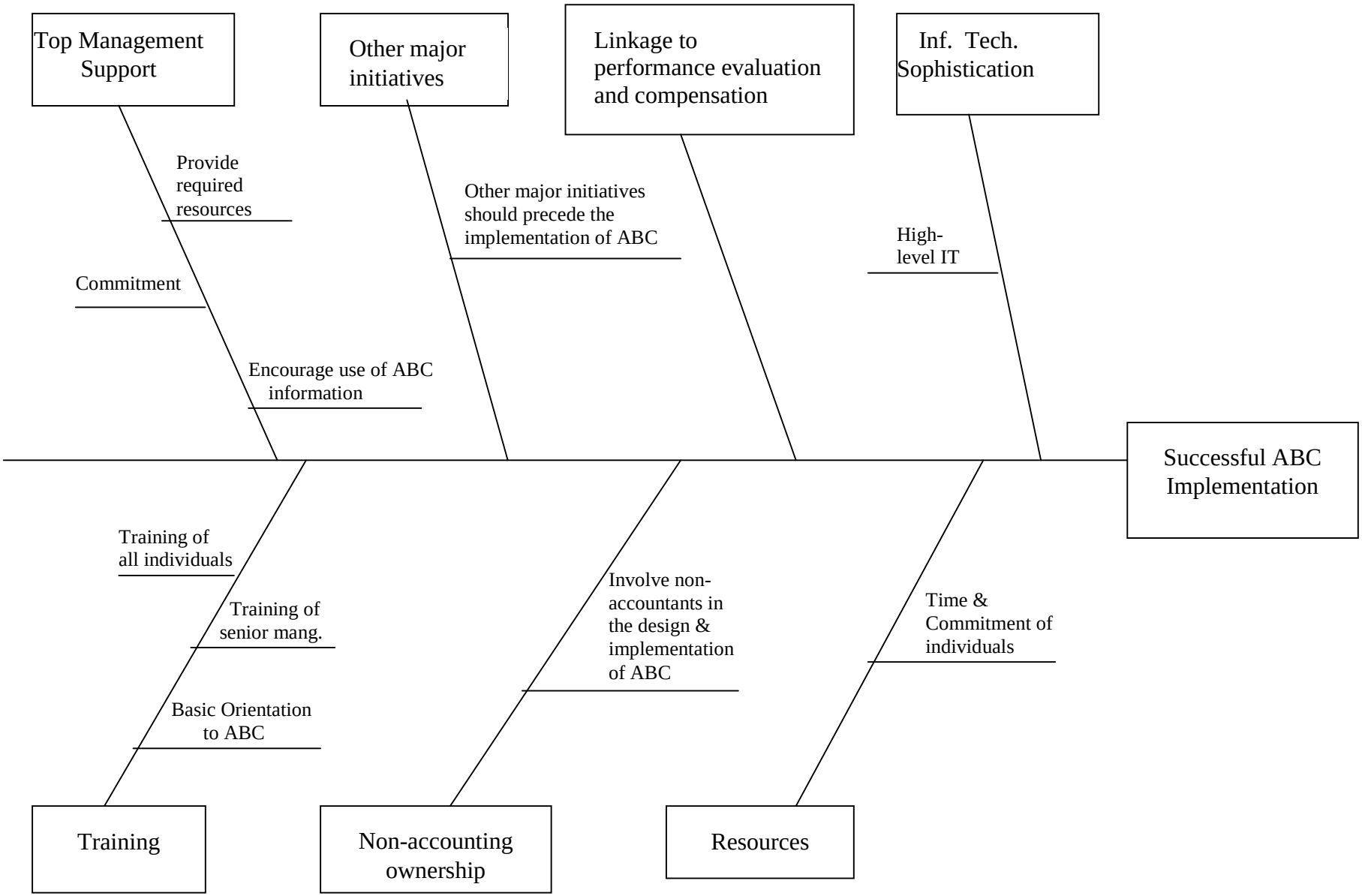
APPENDIXES

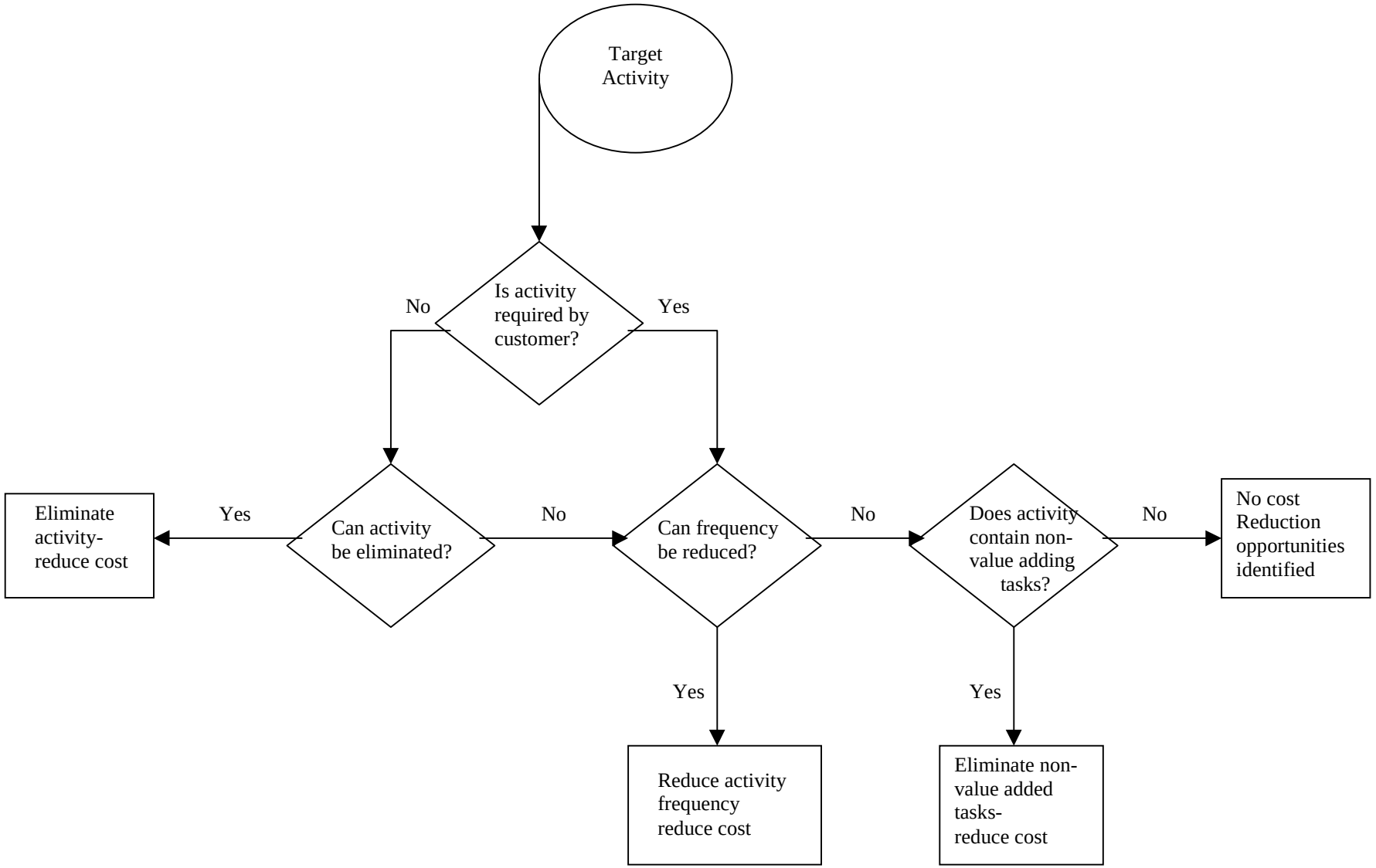
Appendix A. ABC Cost Assignment Model [8, p.23]



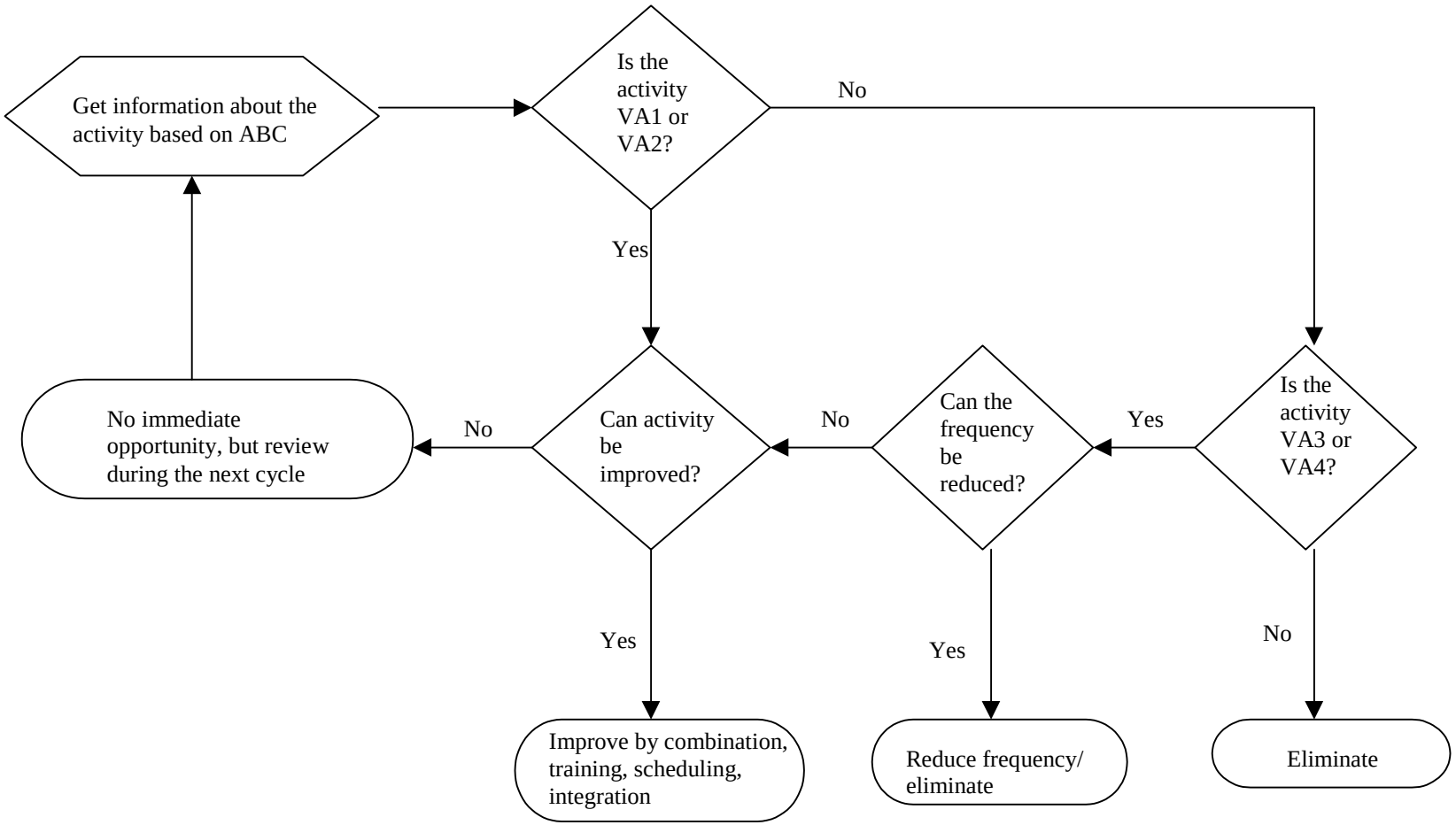
Appendix B. Vital Factors in ABC implementation [3, 31, 51]



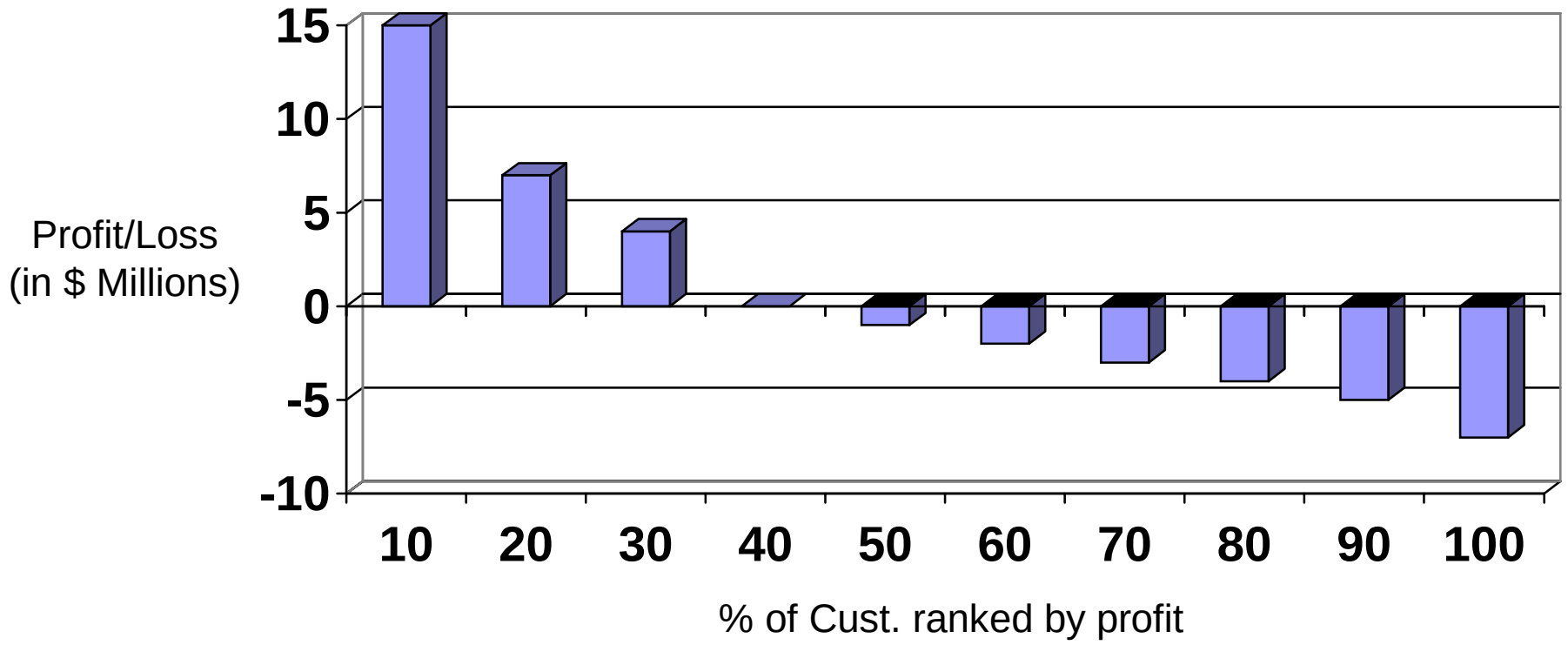
Appendix C. Activity-based cost reduction model [43, p.313]



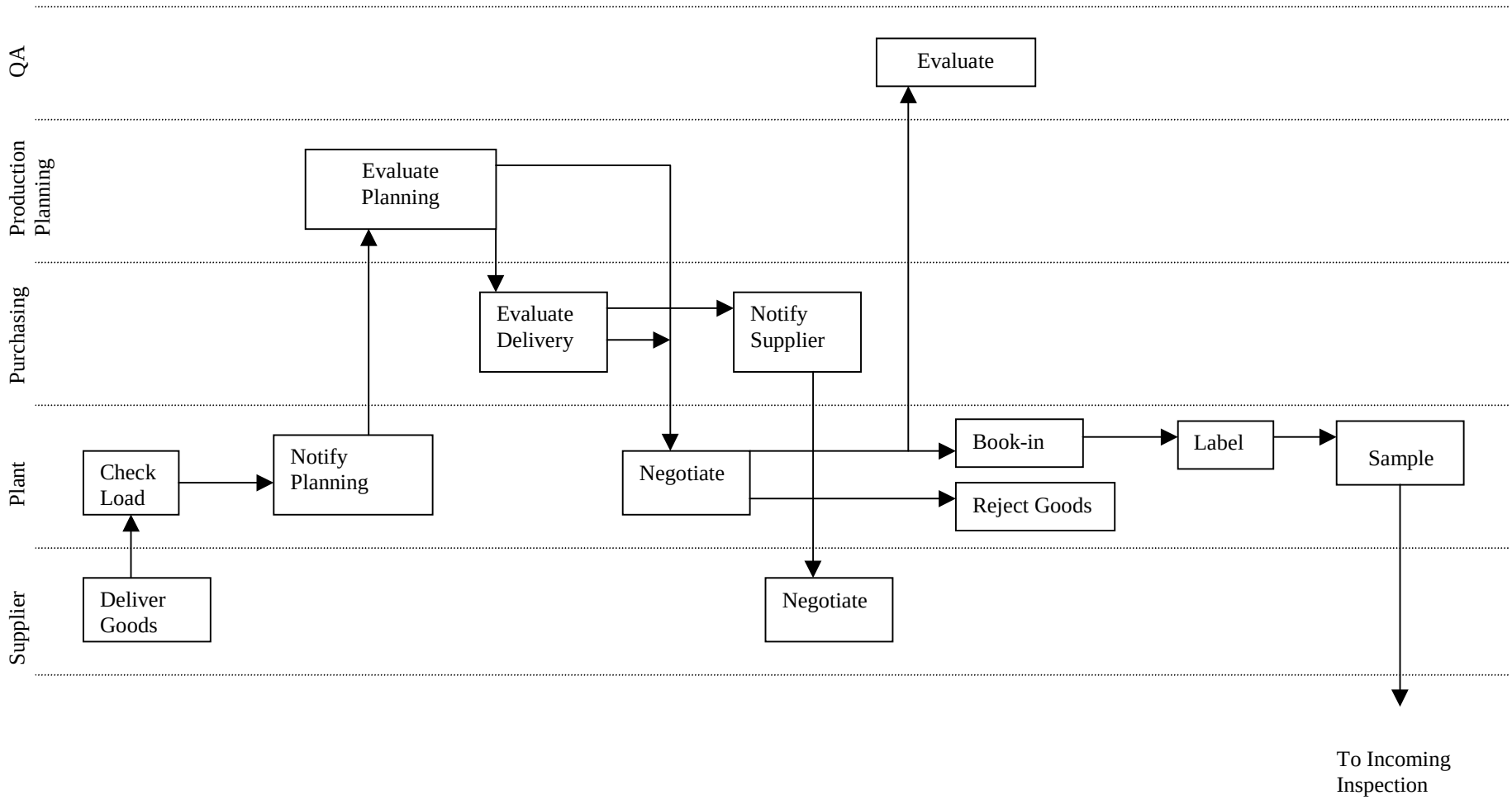
Appendix D. Activity Based Cost Reduction Decision Model which is used in Dayton [44]



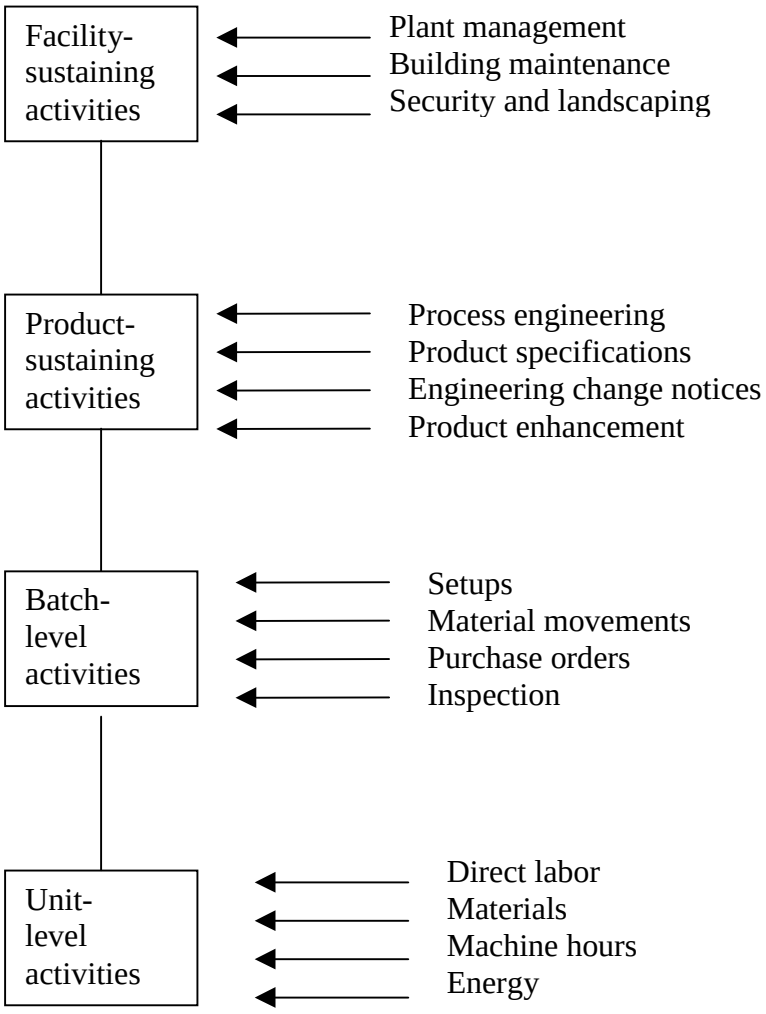
Appendix E. Colter's profits by percentage of customers [43, p.272]



Appendix F. An activity map example showing the extra activities performed when an unexpected consignment is delivered to a plant [39, p.37]



Appendix G. ABC Hierarchical Model [13, p.272]



Appendix H. The mathematical model developed for the XYZ Company by using the traditional costing approach

```
MAX

27X1 + 32X2 + 75X3 - 16X1 - 20X2 - 22X3 - 1X1 - 2X2 - 8X3 - 8.02X1 –

16.04X2 - 64.16X3

st

(1)   256Y1 + 128Y2 + 64Y3 <= 8000

(2)   5777.777778Y1 + 3466.666667Y2  + 2888.888889Y3 <= 260000

(3)   12480Y1 + 7488Y2 + 6240Y3 <= 312000

(4)   5000Y1 + 1000Y2 + 200Y3 <= 75000

(5)   5X1 + 2X2 + 1X3 <= 700000

(6)   0.3125X1 + 0.125X2 + 0.0625X3 <= 50000

(7)   17142.85714Y1 + 3428.571429Y2 + 5485.714286Y3 <= 600000

(8)   1X1 + 2X2 + 8X3 <= 250000

(9)   16X1 + 20X2 + 22X3 <= 6000000

(10)  X1< = 150000

(11)  X2< = 100000

(12)  X3< = 60000

(13)  7500Y1 - X1 = 0

(14)  2500Y2 - X2 = 0

(15)  400Y3 - X3 = 0

(16)  TT1 - 16X1 - 1X1 - 8.02X1 = 0

(17)  TA1 - 256Y1 - 5777.777778Y1 - 12480Y1 - 5000Y1 - 5X1 - 0.3125X1 -
      17142.85714Y1 - 1X1 - 16X1 = 0

(18)  UCT1 - 0.00000888888888888889TT1 = 0

(19)  UCA1 - 0.00000888888888888889TA1 = 0
```

```
generals

X1
X2
X3
Y1
Y2
Y3
END
```

Appendix I. The output of mathematical model developed for the XYZ Company by using the traditional costing approach

```
Integer optimal solution:  Objective =    2.2275000000e+05
Solution time =    0.00 sec.  Iterations = 0  Nodes = 0


CPLEX> dis sol var –

Variable Name           Solution Value
X1                       112500.000000
Y1                           15.000000
TT1                     2814750.000000
TA1                     3120005.773770
UCT1                         25.020000
UCA1                         27.733385

All other variables in the range 1-10 are zero.


CPLEX> dis sol sla –

Constraint Name                 Slack Value
slack c1                          4160.000000
slack c2                        173333.333330
slack c3                        124800.000000
slack c5                        137500.000000
slack c6                         14843.750000
slack c7                        342857.142900
slack c8                        137500.000000
slack c9                       4200000.000000
slack c10                         37500.000000
slack c11                        100000.000000
slack c12                         60000.000000

All other slacks in the range 1-19 are zero.
```

Appendix J. The mathematical model developed for the XYZ Company by using the activity-based costing approach

```
MAX

27X1 + 32X2 + 75X3 - 256Y1 - 128Y2 - 64Y3 - 5777.777778Y1 –
3466.666667Y2 - 2888.888889Y3 - 12480Y1 - 7488Y2 - 6240Y3 - 5000Y1 –
1000Y2 - 200Y3 - 5X1 - 2X2 - 1X3 - 0.3125X1 - 0.125X2 - 0.0625X3 –
17142.85714Y1 - 3428.571429Y2 - 5485.714286Y3 - 1X1 - 2X2 - 8X3 - 16X1
- 20X2 - 22X3


st


(1)   256Y1 + 128Y2 + 64Y3 <= 8000
(2)   5777.777778Y1 + 3466.666667Y2 + 2888.888889Y3 <= 260000
(3)   12480Y1 + 7488Y2 + 6240Y3 <= 312000
(4)   5000Y1 + 1000Y2 + 200Y3 <= 75000
(5)   5X1 + 2X2 + 1X3 <= 700000
(6)   0.3125X1 + 0.125X2 + 0.0625X3 <= 50000
(7)   17142.85714Y1 + 3428.571429Y2 + 5485.714286Y3 <= 600000
(8)   1X1 + 2X2 + 8X3 <= 250000
(9)   16X1 + 20X2 + 22X3 <= 6000000
(10)  X1 <= 150000
(11)  X2 <= 100000
(12)  X3 <= 60000
(13)  7500Y1 - X1 = 0
(14)  2500Y2 - X2 = 0
(15)  400Y3 - X3 = 0
(16)  TA2 - 128Y2 - 3466.666667Y2 - 7488Y2 - 1000Y2 - 2X2 - 0.125X2 -
      3428.571429Y2 - 2X2 - 20X2 = 0
```

```
(17)  TA3 - 64Y3 - 2888.888889Y3 - 6240Y3 - 200Y3 - 1X3 - 0.0625X3 -
      5485.714286Y3 - 8X3 - 22X3 = 0

(18)  UCA2 - 0.00001TA2 = 0

(19)  UCA3 - 0.00125TA3 = 0


generals


X1
X2
X3
Y1
Y2
Y3
END
```

Appendix K. The output of the mathematical model developed for the XYZ Company by using the activity-based costing approach

```
Integer optimal solution:  Objective =    1.7244326981e+05
Solution time =    0.00 sec.  Iterations = 2  Nodes = 0


CPLEX> dis sol var –

Variable Name           Solution Value
X2                       100000.000000
X3                          800.000000
Y2                           40.000000
Y3                            2.000000
TA2                     3032949.523840
TA3                       54607.206350
UCA2                         30.329495
UCA3                         68.259008

All other variables in the range 1-10 are zero.


CPLEX> dis sol sla –

Constraint Name                 Slack Value
slack c1                         2752.000000
slack c2                       115555.555542
slack c4                        34600.000000
slack c5                       499200.000000
slack c6                        37450.000000
slack c7                       451885.714268
slack c8                        43600.000000
slack c9                      3982400.000000
slack c10                      150000.000000
slack c12                       59200.000000

All other slacks in the range 1-19 are zero.
```

Appendix L. The mathematical model developed for the AYBEN Company by using the activity-based costing approach

```
MAX

53X1 + 58X2 + 62X3 + 60X4 + 60X5 - 4.2X1 - 5.95X2 - 5.95X3 - 5.25X4 –
5.95X5 - 1.5X1 - 5X2 - 2X3 - 2X4 - 4X5 - 8X1 - 5X2 - 10X3 - 11X4 - 6X5
- 14X1 - 17.5X2 - 24.5X3 - 17.5X4 - 10.5X5 - 3.2X1 - 4.8X2 - 4X3 - 4X4
- 5.6X5 - 4X1 - 3X2 - 1.5X3 - 2X4 - 2.5X5 - 480Y1 - 300Y2 - 330Y3 –
375Y4 - 270Y5 - 5000Y1 - 3000Y2 - 1800Y3 - 2000Y4 - 2600Y5 - 400Y1 –
480Y2 - 320Y3 - 320Y4 - 360Y5 - 3000Y1 - 2000Y2 - 1500Y3 - 1600Y4 –
1800Y5 - 2500Y1 - 3000Y2 - 2000Y3 - 2000Y4 - 2700Y5 - 1600Y1 - 1200Y2 –
800Y3 - 920Y4 - 1040Y5 - 2000Z1 - 1600Z2 - 3000Z3 - 3400Z4 - 4000Z5 –
200000Z1 - 250000Z2 - 150000Z3 - 180000Z4 - 170000Z5

st

(1)   4.2X1 + 5.95X2 + 5.95X3 + 5.25X4 + 5.95X5 <= 1500000
(2)   1.5X1 + 5X2 + 2X3 + 2X4 + 4X5 <= 800000
(3)   8X1 + 5X2 + 10X3 + 11X4 + 6X5 <= 2300000
(4)   14X1 + 17.5X2 + 24.5X3 + 17.5X4 + 10.5X5 <= 1697500
(5)   3.2X1 + 4.8X2 + 4X3 + 4X4 + 5.6X5 <= 3000000
(6)   4X1 + 3X2 + 1.5X3 + 2X4 + 2.5X5 <= 1050000
(7)   480Y1 + 300Y2 + 330Y3 + 375Y4 + 270Y5 <= 150000
(8)   5000Y1 + 3000Y2 + 1800Y3 + 2000Y4 + 2600Y5 <= 750000
(9)   400Y1 + 480Y2 + 320Y3 + 320Y4 + 360Y5 <= 170000
(10)  3000Y1 + 2000Y2 + 1500Y3 + 1600Y4 + 1800Y5 <= 500000
(11)  2500Y1 + 3000Y2 + 2000Y3 + 2000Y4 + 2700Y5 <= 550000
(12)  1600Y1 + 1200Y2 + 800Y3 + 920Y4 + 1040Y5 <= 350000
(13)  2000Z1 + 1600Z2 + 3000Z3 + 3400Z4 + 4000Z5 <= 80000
(14)  200000Z1 + 250000Z2 + 150000Z3 + 180000Z4 + 170000Z5 <= 1100000
```

```
(15)  X1 <= 200000

(16)  X2 <= 150000

(17)  X3 - 100000Z3 <= 0

(18)  X3 - 30000Z3 >= 0

(19)  X4 + 100000Z3 <= 100000

(20)  X4 + 30000Z3 >= 30000

(21)  X5 <= 80000

(22)  2000Y1 - X1 = 0

(23)  1500Y2 - X2 = 0

(24)  1000Y3 - X3 = 0

(25)  1000Y4 - X4 = 0

(26)  1250Y5 - X5 = 0

(27)  Y1 - 999999999Z1 <= 0

(28)  Y2 - 999999999Z2 <= 0

(29)  Y3 - 999999999Z3 <= 0

(30)  Y4 - 999999999Z4 <= 0

(31)  Y5 - 999999999Z5 <= 0


generals

X1
X2
X3
X4
X5
Y1
Y2
Y3
Y4
Y5


binaries

Z1
Z2
Z3
Z4
Z5
END
```

Appendix M. The output of the mathematical model developed for the AYBEN Company by using the activity-based costing approach

```
Integer optimal solution:  Objective =    1.6580350000e+06
Solution time =    0.00 sec.  Iterations = 23  Nodes = 11


CPLEX> dis sol var –

Variable Name           Solution Value
X4                        49000.000000
X5                        80000.000000
Y4                           49.000000
Y5                           64.000000
Z4                            1.000000
Z5                            1.000000

All other variables in the range 1-15 are zero.


CPLEX> dis sol sla –

Constraint Name                 Slack Value
slack c1                       766750.000000
slack c2                       382000.000000
slack c3                      1281000.000000
slack c5                      2356000.000000
slack c6                       752000.000000
slack c7                       114345.000000
slack c8                       485600.000000
slack c9                       131280.000000
slack c10                      306400.000000
slack c11                      279200.000000
slack c12                      238360.000000
slack c13                       72600.000000
slack c14                      750000.000000
slack c15                      200000.000000
slack c16                      150000.000000
slack c19                       51000.000000
slack c20                      -19000.000000
slack c30                   999999950.000000
slack c31                   999999935.000000

All other slacks in the range 1-31 are zero.
```

Appendix N. The mathematical model developed for the AYBEN Company by considering the activity flexibility option

```
MAX

53X1 + 58X2 + 62X3 + 60X4 + 60X5 - 4.2X1 - 5.95X2 - 5.95X3 - 5.25X4 –
5.95X5 - 1.5X1 - 5X2 - 2X3 - 2X4 - 4X5 - 8X1 - 5X2 - 10X3 - 11X4 - 6X5
- 28000F1 - 14000F2 - 17.5X2 - 24.5X3 - 17.5X4 - 10.5X5 - 6400F1 –
24000F2 - 4.8X2 - 4X3 - 4X4 - 5.6X5 - 4X1 - 3X2 - 1.5X3 - 2X4 - 2.5X5 –
480Y1 - 300Y2 - 330Y3 - 375Y4 - 270Y5 - 5000Y1 - 3000Y2 - 1800Y3 –
2000Y4 - 2600Y5 - 400Y1 - 480Y2 - 320Y3 - 320Y4 - 360Y5 - 3000Y1 –
2000Y2 - 1500Y3 - 1600Y4 - 1800Y5 - 2500Y1 - 3000Y2 - 2000Y3 - 2000Y4 –
2700Y5 - 1600Y1 - 1200Y2 - 800Y3 - 920Y4 - 1040Y5 - 2000Z1 - 1600Z2 –
3000Z3 - 3400Z4 - 4000Z5 - 200000Z1 - 250000Z2 - 150000Z3 - 180000Z4 –
170000Z5

st

(1)   4.2X1 + 5.95X2 + 5.95X3 + 5.25X4 + 5.95X5 <= 1500000
(2)   1.5X1 + 5X2 + 2X3 + 2X4 + 4X5 <= 800000
(3)   8X1 + 5X2 + 10X3 + 11X4 + 6X5 <= 2300000
(4)   28000F1 + 14000F2 + 17.5X2 + 24.5X3 + 17.5X4 + 10.5X5 <= 1697500
(5)   6400F1 + 24000F2 + 4.8X2 + 4X3 + 4X4 + 5.6X5 <= 3000000
(6)   4X1 + 3X2 + 1.5X3 + 2X4 + 2.5X5 <= 1050000
(7)   480Y1 + 300Y2 + 330Y3 + 375Y4 + 270Y5 <= 150000
(8)   5000Y1 + 3000Y2 + 1800Y3 + 2000Y4 + 2600Y5 <= 750000
(9)   400Y1 + 480Y2 + 320Y3 + 320Y4 + 360Y5 <= 170000
(10)  3000Y1 + 2000Y2 + 1500Y3 + 1600Y4 + 1800Y5 <= 500000
```

```
(11)  2500Y1 + 3000Y2 + 2000Y3 + 2000Y4 + 2700Y5 <= 550000

(12)  1600Y1 + 1200Y2 + 800Y3 + 920Y4 + 1040Y5 <= 350000

(13)  2000Z1 + 1600Z2 + 3000Z3 + 3400Z4 + 4000Z5 <= 80000

(14)  200000Z1 + 250000Z2 + 150000Z3 + 180000Z4 + 170000Z5 <= 1100000

(15)  Y1 - F1 - F2 = 0

(16)  X1 <= 200000

(17)  X2 <= 150000

(18)  X3 - 100000Z3 <= 0

(19)  X3 - 30000Z3>= 0

(20)  X4 + 100000Z3 <= 100000

(21)  X4 + 30000Z3>= 30000

(22)  X5 <= 80000

(23)  2000Y1 - X1 = 0

(24)  1500Y2 - X2 = 0

(25)  1000Y3 - X3 = 0

(26)  1000Y4 - X4 = 0

(27)  1250Y5 - X5 = 0

(28)  Y1 - 999999999Z1 <= 0

(29)  Y2 - 999999999Z2 <= 0

(30)  Y3 - 999999999Z3 <= 0

(31)  Y4 - 999999999Z4 <= 0

(32)  Y5 - 999999999Z5 <= 0


generals


X1
X2
X3
X4
X5
Y1
Y2
```

```
Y3
Y4
Y5
F1
F2


binaries

Z1
Z2
Z3
Z4
Z5
END
```

Appendix O. The output of the mathematical model developed for the AYBEN Company by considering the activity flexibility option

```
Integer optimal solution:  Objective =    1.6976300000e+06
Solution time =    0.05 sec.  Iterations = 124  Nodes = 76


CPLEX> dis sol var –

Variable Name           Solution Value
X1                        46000.000000
X4                        30000.000000
X5                        80000.000000
F2                           23.000000
Y1                           23.000000
Y4                           30.000000
Y5                           64.000000
Z1                            1.000000
Z4                            1.000000
Z5                            1.000000

All other variables in the range 1-17 are zero.


CPLEX> dis sol sla –

Constraint Name                 Slack Value
slack c1                     673300.000000
slack c2                     351000.000000
slack c3                    1122000.000000
slack c4                      10500.000000
slack c5                    1880000.000000
slack c6                     606000.000000
slack c7                     110430.000000
slack c8                     408600.000000
slack c9                     128160.000000
slack c10                    267800.000000
slack c11                    259700.000000
slack c12                    219040.000000
slack c13                     70600.000000
slack c14                    550000.000000
slack c16                    154000.000000
slack c17                    150000.000000
slack c20                     70000.000000
slack c28                  999999976.000000
slack c31                  999999969.000000
slack c32                  999999935.000000

All other slacks in the range 1-32 are zero.
```

Appendix P. The mathematical model developed for the AYBEN Company by considering the outsourcing option

```
MAX

53X1 + 58X2 + 62X3 + 60X4 + 60X5 - 4.2X1 - 5.95X2 - 5.95X3 - 5.25X4 –
5.95J1 - 4.9J2 - 1.5X1 - 5X2 - 2X3 - 2X4 - 4X5 - 8X1 - 5X2 - 10X3 –
11X4 - 6X5 - 28000F1 - 14000F2 - 17.5X2 - 24.5X3 - 17.5X4 - 10.5J1 –
6400F1 - 24000F2 - 4.8X2 - 4X3 - 4X4 - 5.6X5 - 4X1 - 3X2 - 1.5X3 - 2X4
- 2.5X5 - 480Y1 - 300Y2 - 330Y3 - 375Y4 - 0.216J1 - 0.168J2 - 5000Y1 –
3000Y2 - 1800Y3 - 2000Y4 - 2600Y5 - 400Y1 - 480Y2 - 320Y3 - 320Y4 –
0.288J1 - 0.352J2 - 3000Y1 - 2000Y2 - 1500Y3 - 1600Y4 - 1800Y5 - 2500Y1
- 3000Y2 - 2000Y3 - 2000Y4 - 2700Y5 - 1600Y1 - 1200Y2 - 800Y3 - 920Y4 -
0.832J1 - 0.704J2 - 2000Z1 - 1600Z2 - 3000Z3 - 3400Z4 - 4000Z5 –
200000Z1 - 250000Z2 - 150000Z3 - 180000Z4 - 170000Z5 - 10000K - 12J2

st

(1)   4.2X1 + 5.95X2 + 5.95X3 + 5.25X4 + 5.95J1 + 4.9J2 <= 1500000
(2)   1.5X1 + 5X2 + 2X3 + 2X4 + 4X5 <= 800000
(3)   8X1 + 5X2 + 10X3 + 11X4 + 6X5 <= 2300000
(4)   28000F1 + 14000F2 + 17.5X2 + 24.5X3 + 17.5X4 + 10.5J1 <= 1697500
(5)   6400F1 + 24000F2 + 4.8X2 + 4X3 + 4X4 + 5.6X5 <= 3000000
(6)   4X1 + 3X2 + 1.5X3 + 2X4 + 2.5X5 <= 1050000
(7)   480Y1 + 300Y2 + 330Y3 + 375Y4 + 0.216J1 + 0.168J2 <= 150000
(8)   5000Y1 + 3000Y2 + 1800Y3 + 2000Y4 + 2600Y5 <= 750000
(9)   400Y1 + 480Y2 + 320Y3 + 320Y4 + 0.288J1 + 0.352J2 <= 170000
(10)  3000Y1 + 2000Y2 + 1500Y3 + 1600Y4 + 1800Y5 <= 500000
(11)  2500Y1 + 3000Y2 + 2000Y3 + 2000Y4 + 2700Y5 <= 550000
```

```
(12)  1600Y1 + 1200Y2 + 800Y3 + 920Y4 + 0.832J1 + 0.704J2 <= 350000

(13)  2000Z1 + 1600Z2 + 3000Z3 + 3400Z4 + 4000Z5 <= 80000

(14)  200000Z1 + 250000Z2 + 150000Z3 + 180000Z4 + 170000Z5 + 10000K <=
      1100000

(15)  Y1 - F1 - F2 = 0

(16)  J1 + 80000K <= 80000

(17)  J2 - 80000K <= 0

(18)  X5 - J1 - J2 = 0

(19)  X1 <= 200000

(20)  X2 <= 150000

(21)  X3 - 100000Z3 <= 0

(22)  X3 - 30000Z3 >= 0

(23)  X4 + 100000Z3 <= 100000

(24)  X4 + 30000Z3 >= 30000

(25)  X5 <= 80000

(26)  2000Y1 - X1 = 0

(27)  1500Y2 - X2 = 0

(28)  1000Y3 - X3 = 0

(29)  1000Y4 - X4 = 0

(30)  1250Y5 - X5 = 0

(31)  Y1 - 999999999Z1 <= 0

(32)  Y2 - 999999999Z2 <= 0

(33)  Y3 - 999999999Z3 <= 0

(34)  Y4 - 999999999Z4 <= 0

(35)  Y5 - 999999999Z5 <= 0


generals


X1
X2
X3
```

```
X4
X5
Y1
Y2
Y3
Y4
Y5
F1
F2
J1
J2


binaries


Z1
Z2
Z3
Z4
Z5
K
END
```

Appendix Q. The output of the mathematical model developed for the AYBEN Company by considering the outsourcing option

```
Integer optimal solution (0.0001/0):  Objective =    2.8377900000e+06
Current MIP best bound =    2.8379856667e+06 (gap = 195.667)
Solution time =    0.03 sec.  Iterations = 75  Nodes = 40


CPLEX> dis sol var –

Variable Name           Solution Value
X1                       166000.000000
X4                        30000.000000
X5                        80000.000000
J2                        80000.000000
F2                           83.000000
Y1                           83.000000
Y4                           30.000000
Y5                           64.000000
Z1                            1.000000
Z4                            1.000000
Z5                            1.000000
K                             1.000000

All other variables in the range 1-20 are zero.


CPLEX> dis sol sla –

Constraint Name                 Slack Value
slack c1                       253300.000000
slack c2                       171000.000000
slack c3                       162000.000000
slack c4                        10500.000000
slack c5                       440000.000000
slack c6                       126000.000000
slack c7                        85470.000000
slack c8                       108600.000000
slack c9                        99040.000000
slack c10                       87800.000000
slack c11                      109700.000000
slack c12                      133280.000000
slack c13                       70600.000000
slack c14                      540000.000000
slack c19                       34000.000000
slack c20                      150000.000000
slack c23                       70000.000000
slack c31                    999999916.000000
slack c34                    999999969.000000
slack c35                    999999935.000000

All other slacks in the range 1-35 are zero.
```

Appendix R. The mathematical model developed for the AYBEN Company by considering fixed costs associated with product 1

```
MAX

53X1 + 58X2 + 62X3 + 60X4 + 60X5 - 4.2X1 - 5.95X2 - 5.95X3 - 5.25X4 –
5.95J1 - 4.9J2 - 1.5X1 - 5X2 - 2X3 - 2X4 - 4X5 - 8X1 - 5X2 - 10X3 –
11X4 - 6X5 - 28000F1 - 14000F2 - 17.5X2 - 24.5X3 - 17.5X4 - 10.5J1 –
6400F1 - 24000F2 - 4.8X2 - 4X3 - 4X4 - 5.6X5 - 4X1 - 3X2 - 1.5X3 - 2X4
- 2.5X5 - 480Y1 - 300Y2 - 330Y3 - 375Y4 - 0.216J1 - 0.168J2 - 5000Y1 –
3000Y2 - 1800Y3 - 2000Y4 - 2600Y5 - 400Y1 - 480Y2 - 320Y3 - 320Y4 –
0.288J1 - 0.352J2 - 3000Y1 - 2000Y2  - 1500Y3 - 1600Y4 - 1800Y5 –
2500Y1 - 3000Y2 - 2000Y3 - 2000Y4 - 2700Y5 - 1600Y1 - 1200Y2 - 800Y3 –
920Y4 - 0.832J1 - 0.704J2 - 2000Z1 - 1600Z2 - 3000Z3 - 3400Z4 - 4000Z5
- 200000Z1 - 250000Z2 - 150000Z3 - 180000Z4 - 170000Z5 - 10000K - 12J2
- 20000C1 - 96000C2

st

(1)   4.2X1 + 5.95X2 + 5.95X3 + 5.25X4 + 5.95J1 + 4.9J2 <= 1500000
(2)   1.5X1 + 5X2 + 2X3 + 2X4 + 4X5 <= 800000
(3)   8X1 + 5X2 + 10X3 + 11X4 + 6X5 <= 2300000
(4)   28000F1 + 14000F2 + 17.5X2 + 24.5X3 + 17.5X4 + 10.5J1 <= 1697500
(5)   6400F1 + 24000F2 + 4.8X2 + 4X3 + 4X4 + 5.6X5 <= 3000000
(6)   4X1 + 3X2 + 1.5X3 + 2X4 + 2.5X5 <= 1050000
(7)   480Y1 + 300Y2 + 330Y3 + 375Y4 + 0.216J1 + 0.168J2 <= 150000
(8)   5000Y1 + 3000Y2 + 1800Y3 + 2000Y4 + 2600Y5 <= 750000
(9)   400Y1 + 480Y2 + 320Y3 + 320Y4 + 0.288J1 + 0.352J2 <= 170000
(10)  3000Y1 + 2000Y2 + 1500Y3 + 1600Y4 + 1800Y5 <= 500000
(11)  2500Y1 + 3000Y2 + 2000Y3 + 2000Y4 + 2700Y5 <= 550000
```

(12) 1600Y1 + 1200Y2 + 800Y3 + 920Y4 + 0.832J1 + 0.704J2 <= 350000

(13) 2000Z1 + 1600Z2 + 3000Z3 + 3400Z4 + 4000Z5 <= 80000

(14) 200000Z1 + 250000Z2 + 150000Z3 + 180000Z4 + 170000Z5 + 10000K <= 1100000

(15) Y1 - F1 - F2 = 0

(16) J1 + 80000K <= 80000

(17) J2 - 80000K <= 0

(18) X5 - J1 - J2 = 0

(19) X1 - 150000C1 <= 50000

(20) X1 - 50000C2 <= 150000

(21) C1 - C2 >= 0

(22) X1 <= 200000

(23) X2 <= 150000

(24) X3 - 100000Z3 <= 0

(25) X3 - 30000Z3 >= 0

(26) X4 + 100000Z3 <= 100000

(27) X4 + 30000Z3 >= 30000

(28) X5 <= 80000

(29) 2000Y1 - X1 = 0

(30) 1500Y2 - X2 = 0

(31) 1000Y3 - X3 = 0

(32) 1000Y4 - X4 = 0

(33) 1250Y5 - X5 = 0

(34) Y1 - 999999999Z1 <= 0

(35) Y2 - 999999999Z2 <= 0

(36) Y3 - 999999999Z3 <= 0

(37) Y4 - 999999999Z4 <= 0

(38) Y5 - 999999999Z5 <= 0

```
generals


X1
X2
X3
X4
X5
Y1
Y2
Y3
Y4
Y5
F1
F2
J1
J2


binaries


Z1
Z2
Z3
Z4
Z5
K
C1
C2
END
```

Appendix S. The output of the mathematical model developed for the AYBEN Company by considering fixed costs associated with product 1

```
Integer optimal solution:  Objective =    2.7380750000e+06
Solution time =    0.01 sec.  Iterations = 55  Nodes = 24


CPLEX> dis sol var –

Variable Name           Solution Value
X1                       150000.000000
X4                        37000.000000
X5                        80000.000000
J2                        80000.000000
F2                           75.000000
Y1                           75.000000
Y4                           37.000000
Y5                           64.000000
Z1                            1.000000
Z4                            1.000000
Z5                            1.000000
K                             1.000000
C1                            1.000000

All other variables in the range 1-22 are zero.

CPLEX> dis sol sla -
Constraint Name                 Slack Value
slack c1                       283750.000000
slack c2                       181000.000000
slack c3                       213000.000000
slack c4                           -0.000000
slack c5                       604000.000000
slack c6                       176000.000000
slack c7                        86685.000000
slack c8                       134600.000000
slack c9                       100000.000000
slack c10                      100600.000000
slack c11                      115700.000000
slack c12                      139640.000000
slack c13                       70600.000000
slack c14                      540000.000000
slack c19                       50000.000000
slack c21                          -1.000000
slack c22                       50000.000000
slack c23                      150000.000000
slack c26                       63000.000000
slack c27                       -7000.000000
artif c32                           0.000000
slack c34                   999999924.000000
slack c37                   999999962.000000
slack c38                   999999935.000000

All other slacks in the range 1-38 are zero.
```

Appendix T. The multi-period product-mix decision model for the AYBEN Company

MAX

53X11+ 58X12+ 60X13+ 58X14+ 58X21+ 56X22+ 52X23+ 60X24+ 62X31+ 60X32+ 58X33+ 61X34+ 60X41+ 58X42+ 55X43+ 58X44+ 60X51+ 50X52+ 48X53+ 63X54 -4.2X11- 5.95X21- 5.95X31- 5.25X41- 5.95J11- 4.9J21- 4.2X12- 5.95X22- 5.95X32- 5.25X42-5.95J12- 4.9J22- 4.2X13- 5.95X23- 5.95X33- 5.25X43- 5.95J13- 4.9J23- 4.2X14- 5.95X24- 5.95X34- 5.25X44- 5.95J14- 4.9J24- 1.5X11- 5X21- 2X31- 2X41- 4X51- 1.5X12- 5X22- 2X32- 2X42- 4X52- 1.5X13- 5X23- 2X33- 2X43- 4X53- 1.5X14- 5X24- 2X34- 2X44- 4X54- 8X11- 5X21- 10X31- 11X41- 6X51- 8X12- 5X22- 10X32- 11X42- 6X52- 8X13- 5X23- 10X33- 11X43- 6X53- 8X14- 5X24- 10X34- 11X44- 6X54- 28000F11- 14000F21- 17.5X21- 24.5X31- 17.5X41- 10.5J11- 28000F12- 14000F22- 17.5X22- 24.5X32- 17.5X42- 10.5J12- 28000F13- 14000F23- 17.5X23- 24.5X33- 17.5X43- 10.5J13- 28000F14- 14000F24- 17.5X24- 24.5X34- 17.5X44- 10.5J14- 6400F11- 24000F21- 4.8X21- 4X31- 4X41- 5.6X51- 6400F12- 24000F22- 4.8X22- 4X32- 4X42- 5.6X52- 6400F13- 24000F23- 4.8X23- 4X33- 4X43- 5.6X53- 6400F14- 24000F24- 4.8X24- 4X34- 4X44- 5.6X54- 4X11- 3X21- 1.5X31- 2X41- 2.5X51- 4X12- 3X22- 1.5X32- 2X42- 2.5X52- 4X13- 3X23- 1.5X33- 2X43- 2.5X53- 4X14- 3X24- 1.5X34- 2X44- 2.5X54- 480Y11- 300Y21- 330Y31- 375Y41- 0.216J11- 0.168J21- 480Y12- 300Y22- 330Y32- 375Y42- 0.216J12- 0.168J22- 480Y13- 300Y23- 330Y33- 375Y43- 0.216J13- 0.168J23- 480Y14- 300Y24- 330Y34- 375Y44- 0.216J14- 0.168J24- 5000Y11- 3000Y21- 1800Y31- 2000Y41- 2600Y51- 5000Y12- 3000Y22- 1800Y32- 2000Y42- 2600Y52- 5000Y13- 3000Y23- 1800Y33- 2000Y43- 2600Y53- 5000Y14- 3000Y24- 1800Y34- 2000Y44- 2600Y54- 400Y11- 480Y21- 320Y31- 320Y41- 0.288J11-

0.352J21- 400Y12- 480Y22- 320Y32- 320Y42- 0.288J12- 0.352J22- 400Y13-

480Y23- 320Y33- 320Y43- 0.288J13- 0.352J23- 400Y14- 480Y24- 320Y34-

320Y44- 0.288J14- 0.352J24- 3000Y11- 2000Y21- 1500Y31- 1600Y41-

1800Y51- 3000Y12- 2000Y22- 1500Y32- 1600Y42- 1800Y52- 3000Y13- 2000Y23-

1500Y33- 1600Y43- 1800Y53- 3000Y14- 2000Y24- 1500Y34- 1600Y44- 1800Y54-

2500Y11- 3000Y21- 2000Y31- 2000Y41- 2700Y51- 2500Y12- 3000Y22- 2000Y32-

2000Y42- 2700Y52- 2500Y13- 3000Y23- 2000Y33- 2000Y43- 2700Y53- 2500Y14-

3000Y24- 2000Y34- 2000Y44- 2700Y54- 1600Y11- 1200Y21- 800Y31- 920Y41-

0.832J11- 0.704J21- 1600Y12- 1200Y22- 800Y32- 920Y42- 0.832J12-

0.704J22- 1600Y13- 1200Y23- 800Y33- 920Y43- 0.832J13- 0.704J23-

1600Y14- 1200Y24- 800Y34- 920Y44- 0.832J14- 0.704J24- 2000Z11- 1600Z21-

3000Z31- 3400Z41- 4000Z51- 2000Z12- 1600Z22- 3000Z32- 3400Z42- 4000Z52-

2000Z13- 1600Z23- 3000Z33- 3400Z43- 4000Z53- 2000Z14- 1600Z24- 3000Z34-

3400Z44- 4000Z54- 200000Z11- 250000Z21- 150000Z31- 180000Z41-

170000Z51- 10000K- 200000Z12- 250000Z22- 150000Z32- 180000Z42-

170000Z52- 10000K- 200000Z13- 250000Z23- 150000Z33- 180000Z43-

170000Z53- 10000K- 200000Z14- 250000Z24- 150000Z34- 180000Z44-

170000Z54- 10000K- 12J21- 12J22- 12J23- 12J24- 20000C11- 20000C12-

20000C13- 20000C14- 96000C21- 96000C22 - 96000C23- 96000C24

st.

(1) 4.2X11+ 5.95X21+ 5.95X31+ 5.25X41+ 5.95J11+ 4.9J21<= 1500000
(2) 4.2X12+ 5.95X22+ 5.95X32+ 5.25X42+ 5.95J12+ 4.9J22<= 1500000
(3) 4.2X13+ 5.95X23+ 5.95X33+ 5.25X43+ 5.95J13+ 4.9J23<= 1500000
(4) 4.2X14+ 5.95X24+ 5.95X34+ 5.25X44+ 5.95J14+ 4.9J24<= 1500000

(5) 1.5X11+ 5X21+ 2X31+ 2X41+ 4X51<= 800000
(6) 1.5X12+ 5X22+ 2X32+ 2X42+ 4X52<= 800000
(7) 1.5X13+ 5X23+ 2X33+ 2X43+ 4X53<= 800000
(8) 1.5X14+ 5X24+ 2X34+ 2X44+ 4X54<= 800000

```
(9)   8X11+ 5X21+ 10X31+ 11X41+ 6X51<= 2300000
(10)  8X12+ 5X22+ 10X32+ 11X42+ 6X52<= 2300000
(11)  8X13+ 5X23+ 10X33+ 11X43+ 6X53<= 2300000
(12)  8X14+ 5X24+ 10X34+ 11X44+ 6X54<= 2300000


(13)  28000F11+ 14000F21+ 17.5X21+ 24.5X31+ 17.5X41+ 10.5J11<= 1697500
(14)  28000F12+ 14000F22+ 17.5X22+ 24.5X32+ 17.5X42+ 10.5J12<= 1697500
(15)  28000F13+ 14000F23+ 17.5X23+ 24.5X33+ 17.5X43+ 10.5J13<= 1697500
(16)  28000F14+ 14000F24+ 17.5X24+ 24.5X34+ 17.5X44+ 10.5J14<= 1697500


(17)  6400F11+ 24000F21+ 4.8X21+ 4X31+ 4X41+ 5.6X51<= 3000000
(18)  6400F12+ 24000F22+ 4.8X22+ 4X32+ 4X42+ 5.6X52<= 3000000
(19)  6400F13+ 24000F23+ 4.8X23+ 4X33+ 4X43+ 5.6X53<= 3000000
(20)  6400F14+ 24000F24+ 4.8X24+ 4X34+ 4X44+ 5.6X54<= 3000000


(21)  4X11+ 3X21+ 1.5X31+ 2X41+ 2.5X51<= 1050000
(22)  4X12+ 3X22+ 1.5X32+ 2X42+ 2.5X52<= 1050000
(23)  4X13+ 3X23+ 1.5X33+ 2X43+ 2.5X53<= 1050000
(24)  4X14+ 3X24+ 1.5X34+ 2X44+ 2.5X54<= 1050000


(25)  480Y11+ 300Y21+ 330Y31+ 375Y41+ 0.216J11+ 0.168J21<= 150000
(26)  480Y12+ 300Y22+ 330Y32+ 375Y42+ 0.216J12+ 0.168J22<= 150000
(27)  480Y13+ 300Y23+ 330Y33+ 375Y43+ 0.216J13+ 0.168J23<= 150000
(28)  480Y14+ 300Y24+ 330Y34+ 375Y44+ 0.216J14+ 0.168J24<= 150000


(29)  5000Y11+ 3000Y21+ 1800Y31+ 2000Y41+ 2600Y51<= 750000
(30)  5000Y12+ 3000Y22+ 1800Y32+ 2000Y42+ 2600Y52<= 750000
(31)  5000Y13+ 3000Y23+ 1800Y33+ 2000Y43+ 2600Y53<= 750000
(32)  5000Y14+ 3000Y24+ 1800Y34+ 2000Y44+ 2600Y54<= 750000


(33)  400Y11+ 480Y21+ 320Y31+ 320Y41+ 0.288J11+ 0.352J21<= 170000
(34)  400Y12+ 480Y22+ 320Y32+ 320Y42+ 0.288J12+ 0.352J22<= 170000
(35)  400Y13+ 480Y23+ 320Y33+ 320Y43+ 0.288J13+ 0.352J23<= 170000
(36)  400Y14+ 480Y24+ 320Y34+ 320Y44+ 0.288J14+ 0.352J24<= 170000


(37)  3000Y11+ 2000Y21+ 1500Y31+ 1600Y41+ 1800Y51<= 500000
(38)  3000Y12+ 2000Y22+ 1500Y32+ 1600Y42+ 1800Y52<= 500000
(39)  3000Y13+ 2000Y23+ 1500Y33+ 1600Y43+ 1800Y53<= 500000
(40)  3000Y14+ 2000Y24+ 1500Y34+ 1600Y44+ 1800Y54<= 500000
```

```
(41)  2500Y11+ 3000Y21+ 2000Y31+ 2000Y41+ 2700Y51<= 550000
(42)  2500Y12+ 3000Y22+ 2000Y32+ 2000Y42+ 2700Y52<= 550000
(43)  2500Y13+ 3000Y23+ 2000Y33+ 2000Y43+ 2700Y53<= 550000
(44)  2500Y14+ 3000Y24+ 2000Y34+ 2000Y44+ 2700Y54<= 550000


(45)  1600Y11+ 1200Y21+ 800Y31+ 920Y41+ 0.832J11+ 0.704J21<= 350000
(46)  1600Y12+ 1200Y22+ 800Y32+ 920Y42+ 0.832J12+ 0.704J22<= 350000
(47)  1600Y13+ 1200Y23+ 800Y33+ 920Y43+ 0.832J13+ 0.704J23<= 350000
(48)  1600Y14+ 1200Y24+ 800Y34+ 920Y44+ 0.832J14+ 0.704J24<= 350000


(49)  2000Z11+ 1600Z21+ 3000Z31+ 3400Z41+ 4000Z51<= 80000
(50)  2000Z12+ 1600Z22+ 3000Z32+ 3400Z42+ 4000Z52<= 80000
(51)  2000Z13+ 1600Z23+ 3000Z33+ 3400Z43+ 4000Z53<= 80000
(52)  2000Z14+ 1600Z24+ 3000Z34+ 3400Z44+ 4000Z54<= 80000


(53)  200000Z11+ 250000Z21+ 150000Z31+ 180000Z41+ 170000Z51+ 10000K<=
      1100000
(54)  200000Z12+ 250000Z22+ 150000Z32+ 180000Z42+ 170000Z52+ 10000K<=
      1100000
(55)  200000Z13+ 250000Z23+ 150000Z33+ 180000Z43+ 170000Z53+ 10000K<=
      1100000
(56)  200000Z14+ 250000Z24+ 150000Z34+ 180000Z44+ 170000Z54+ 10000K<=
      1100000


(57)  Y11- F11- F21= 0
(58)  Y12- F12- F22= 0
(59)  Y13- F13- F23= 0
(60)  Y14- F14- F24= 0


(61)  J11+ J12+ J13+ J14+ 210000K<= 210000
(62)  J21+ J22+ J23+ J24- 210000K<= 0


(63)  X51- J11- J21= 0
(64)  X52- J12- J22= 0
(65)  X53- J13- J23= 0
(66)  X54- J14- J24= 0


(67)  X11- 150000C11<= 50000
(68)  X12- 150000C12<= 50000
(69)  X13- 150000C13<= 50000
(70)  X14- 150000C14<= 50000
```

```
(71)  X11- 50000C21<= 150000
(72)  X12- 50000C22<= 150000
(73)  X13- 50000C23<= 150000
(74)  X14- 50000C24<= 150000


(75)  C11- C21>= 0
(76)  C12- C22>= 0
(77)  C13- C23>= 0
(78)  C14- C24>= 0


(79)  X11<= 200000
(80)  X12<= 20000
(81)  X13<= 200000
(82)  X14<= 25000


(83)  X21<= 150000
(84)  X22<= 120000
(85)  X23<= 100000
(86)  X24<= 160000


(87)  X31- 100000Z31<= 0
(88)  X32- 15000Z32<= 0
(89)  X33- 7000Z33<= 0
(90)  X34- 20000Z34<= 0


(91)  X31- 30000Z31>= 0
(92)  X32- 12000Z32>= 0
(93)  X33- 5000Z33>= 0
(94)  X34- 15000Z34>= 0


(95)  X41+ 100000Z31<= 100000
(96)  X42+ 15000Z32<= 15000
(97)  X43+ 7000Z33<= 7000
(98)  X44+ 20000Z34<= 20000


(99)  X41+ 30000Z31>= 30000
(100) X42+ 12000Z32>= 12000
(101) X43+ 5000Z33>= 5000
(102) X44+ 15000Z34>= 15000
```

```
(103) X51<= 80000
(104) X52<= 20000
(105) X53<= 10000
(106) X54<= 100000


(107) 2000Y11- X11= 0
(108) 2000Y12- X12= 0
(109) 2000Y13- X13= 0
(110) 2000Y14- X14= 0


(111) 1500Y21- X21= 0
(112) 1500Y22- X22= 0
(113) 1500Y23- X23= 0
(114) 1500Y24- X24= 0


(115) 1000Y31- X31= 0
(116) 1000Y32- X32= 0
(117) 1000Y33- X33= 0
(118) 1000Y34- X34= 0


(119) 1000Y41- X41= 0
(120) 1000Y42- X42= 0
(121) 1000Y43- X43= 0
(122) 1000Y44- X44= 0


(123) 1250Y51- X51= 0
(124) 1250Y52- X52= 0
(125) 1250Y53- X53= 0
(126) 1250Y54- X54= 0


(127) Y11- 999999999Z11<= 0
(128) Y12- 999999999Z12<= 0
(129) Y13- 999999999Z13<= 0
(130) Y14- 999999999Z14<= 0


(131) Y21- 999999999Z21<= 0
(132) Y22- 999999999Z22<= 0
(133) Y23- 999999999Z23<= 0
(134) Y24- 999999999Z24<= 0
```

```
(135) Y31- 999999999Z31<= 0
(136) Y32- 999999999Z32<= 0
(137) Y33- 999999999Z33<= 0
(138) Y34- 999999999Z34<= 0


(139) Y41- 999999999Z41<= 0
(140) Y42- 999999999Z42<= 0
(141) Y43- 999999999Z43<= 0
(142) Y44- 999999999Z44<= 0


(143) Y51- 999999999Z51<= 0
(144) Y52- 999999999Z52<= 0
(145) Y53- 999999999Z53<= 0
(146) Y54- 999999999Z54<= 0


generals


X11
X12
X13
X14
X21
X22
X23
X24
X31
X32
X33
X34
X41
X42
X43
X44
X51
X52
X53
X54
Y11
Y12
Y13
Y14
Y21
Y22
Y23
Y24
Y31
Y32
Y33
Y34
Y41
```

```
Y42
Y43
Y44
Y51
Y52
Y53
Y54
F11
F12
F13
F14
F21
F22
F23
F24
J11
J12
J13
J14
J21
J22
J23
J24

binaries


Z11
Z12
Z13
Z14
Z21
Z22
Z23
Z24
Z31
Z32
Z33
Z34
Z41
Z42
Z43
Z44
Z51
Z52
Z53
Z54
K
C11
C12
C13
C14
C21
C22
C23
C24
END
```

Appendix U. The output of the multi-period product-mix decision model developed for the AYBEN Company

```
Integer optimal solution (0.0001/0):  Objective =    8.6774900000e+06
Current MIP best bound =    8.6776673333e+06 (gap = 177.333)
Solution time =    0.13 sec.  Iterations = 279  Nodes = 143 (2)


CPLEX> dis sol var –

Variable Name           Solution Value
X11                      150000.000000
X12                       20000.000000
X13                      200000.000000
X14                       24000.000000
X22                       75000.000000
X24                       64500.000000
X33                        5000.000000
X41                       37000.000000
X42                       14000.000000
X44                       20000.000000
X51                       80000.000000
X54                      100000.000000
J21                       80000.000000
J24                      100000.000000
F21                          75.000000
F22                          10.000000
F13                          12.000000
F23                          88.000000
F14                           3.000000
F24                           9.000000
Y11                          75.000000
Y41                          37.000000
Y12                          10.000000
Y22                          50.000000
Y42                          14.000000
Y13                         100.000000
Y33                           5.000000
Y14                          12.000000
Y24                          43.000000
Y44                          20.000000
Y51                          64.000000
Y54                          80.000000
Z11                           1.000000
Z41                           1.000000
Z51                           1.000000
Z12                           1.000000
Z22                           1.000000
Z42                           1.000000
Z13                           1.000000
Z33                           1.000000
Z14                           1.000000
Z24                           1.000000
```

```
Z44                            1.000000
Z54                            1.000000
K                              1.000000
C11                            1.000000
C13                            1.000000
C23                            1.000000

All other variables in the range 1-85 are zero.


CPLEX> dis sol sla –

Constraint Name                  Slack Value
slack c1                       283750.000000
slack c2                       896250.000000
slack c3                       630250.000000
slack c4                       420425.000000
slack c5                       181000.000000
slack c6                       367000.000000
slack c7                       490000.000000
slack c8                         1500.000000
slack c9                       213000.000000
slack c10                     1611000.000000
slack c11                      650000.000000
slack c12                      965500.000000
slack c13                          -0.000000
slack c14                           0.000000
slack c15                        7000.000000
slack c16                        8750.000000
slack c17                      604000.000000
slack c18                     2344000.000000
slack c19                      791200.000000
slack c20                     1815200.000000
slack c21                      176000.000000
slack c22                      717000.000000
slack c23                      242500.000000
slack c24                      470500.000000
slack c25                       86685.000000
slack c26                      124950.000000
slack c27                      100350.000000
slack c28                      107040.000000
slack c29                      134600.000000
slack c30                      522000.000000
slack c31                      241000.000000
slack c32                      313000.000000
slack c33                      100000.000000
slack c34                      137520.000000
slack c35                      128400.000000
slack c36                      102960.000000
slack c37                      100600.000000
slack c38                      347600.000000
slack c39                      192500.000000
slack c40                      202000.000000
slack c41                      115700.000000
```

```
slack c42                      347000.000000
slack c43                      290000.000000
slack c44                      135000.000000
slack c45                      139640.000000
slack c46                      261120.000000
slack c47                      186000.000000
slack c48                      190400.000000
slack c49                       70600.000000
slack c50                       73000.000000
slack c51                       75000.000000
slack c52                       69000.000000
slack c53                      540000.000000
slack c54                      460000.000000
slack c55                      740000.000000
slack c56                      290000.000000
slack c62                       30000.000000
slack c67                       50000.000000
slack c68                       30000.000000
slack c70                       26000.000000
slack c72                      130000.000000
slack c73                           0.000000
slack c74                      126000.000000
slack c75                          -1.000000
slack c79                       50000.000000
slack c81                           0.000000
slack c82                        1000.000000
slack c83                      150000.000000
slack c84                       45000.000000
slack c85                      100000.000000
slack c86                       95500.000000
slack c89                        2000.000000
slack c95                       63000.000000
slack c96                        1000.000000
slack c98                           0.000000
slack c99                       -7000.000000
slack c100                      -2000.000000
slack c102                      -5000.000000
slack c104                      20000.000000
slack c105                      10000.000000
artif c110                         -0.000000
artif c114                          0.000000
artif c119                          0.000000
artif c122                         -0.000000
slack c127                  999999924.000000
slack c128                  999999989.000000
slack c129                  999999899.000000
slack c130                  999999987.000000
slack c132                  999999949.000000
slack c134                  999999956.000000
slack c137                  999999994.000000
slack c139                  999999962.000000
slack c140                  999999985.000000
slack c142                  999999979.000000
slack c143                  999999935.000000
slack c146                  999999919.000000

All other slacks in the range 1-146 are zero.
```

Appendix V. The mathematical model developed for the GUROTO Company

```
MAX
8500X11+ 8000X12+ 8800X13+ 9000X14+ 14000X21+ 13000X22+ 14300X23+
14500X24+ 16000X31+ 15500X32+ 15600X33+ 16500X34+ 23500X41+ 24000X42+
21000X43+ 20000X44+ 27000X51+ 28000X52+ 26000X53+ 23000X54- 500X11-
1500X21- 1100X31- 1500X41- 1600X51- 500X12- 1500X22- 1100X32- 1500X42-
1600X52- 500X13- 1500X23- 1100X33- 1500X43- 1600X53- 500X14- 1500X24-
1100X34- 1500X44- 1600X54- 1500X11- 3500X21- 3800X31- 7000X41- 7500X51-
1500X12- 3500X22- 3800X32- 7000X42- 7500X52- 1500X13- 3500X23- 3800X33-
7000X43- 7500X53- 1500X14- 3500X24- 3800X34- 7000X44- 7500X54- 720X11-
900X21- 942X31- 1092X41- 1170X51- 720X12- 900X22- 942X32- 1092X42-
1170X52- 720X13- 900X23- 942X33- 1092X43- 1170X53- 720X14- 900X24-
942X34- 1092X44- 1170X54- 800X11- 1200X21- 1320X31- 1680X41- 1800X51-
800X12- 1200X22- 1320X32- 1680X42- 1800X52- 800X13- 1200X23- 1320X33-
1680X43- 1800X53- 800X14- 1200X24- 1320X34- 1680X44- 1800X54- 500X11-
600X21- 620X31- 700X41- 750X51- 500X12- 600X22- 620X32- 700X42- 750X52-
500X13- 600X23- 620X33- 700X43- 750X53- 500X14- 600X24- 620X34- 700X44-
750X54- 200X11- 280X21- 304X31- 360X41- 384X51- 200X12- 280X22- 304X32-
360X42- 384X52- 200X13- 280X23- 304X33- 360X43- 384X53- 200X14- 280X24-
304X34- 360X44- 384X54- 150X11- 240X21- 270X31- 345X41- 375X51- 150X12-
240X22- 270X32- 345X42- 375X52- 150X13- 240X23- 270X33- 345X43- 375X53-
150X14- 240X24- 270X34- 345X44- 375X54- 500X11- 560X21- 600X31- 640X41-
660X51- 500X12- 560X22- 600X32- 640X42- 660X52- 500X13- 560X23- 600X33-
640X43- 660X53- 500X14- 560X24- 600X34- 640X44- 660X54- 580X11- 720X21-
760X31- 920X41- 1000X51- 580X12- 720X22- 760X32- 920X42- 1000X52-
580X13- 720X23- 760X33- 920X43- 1000X53- 580X14- 720X24- 760X34- 920X44
```

```
- 1000X54- 100X11- 100X21- 100X31- 200X41- 200X51- 100X12- 100X22-
100X32- 200X42- 200X52- 100X13- 100X23- 100X33- 200X43- 200X53- 100X14-
100X24- 100X34- 200X44- 200X54- 375X11- 500X21- 500X31- 625X41- 625X51-
375X12- 500X22- 500X32- 625X42- 625X52- 375X13- 500X23- 500X33- 625X43-
625X53- 375X14- 500X24- 500X34- 625X44- 625X54- 80000Z11- 88000Z21-
80000Z31- 92000Z41- 100000Z51- 80000Z12- 88000Z22- 80000Z32- 92000Z42-
100000Z52- 80000Z13- 88000Z23- 80000Z33- 92000Z43- 100000Z53- 80000Z14-
88000Z24- 80000Z34- 92000Z44- 100000Z54- 150000Z11- 225000Z21-
270000Z31- 330000Z41- 360000Z51- 150000Z12- 225000Z22- 270000Z32-
330000Z42- 360000Z52- 150000Z13- 225000Z23- 270000Z33- 330000Z43-
360000Z53- 150000Z14- 225000Z24- 270000Z34- 330000Z44- 360000Z54


st.


(1)   500X11+ 1500X21+ 1100X31+ 1500X41+ 1600X51<= 1000000
(2)   500X12+ 1500X22+ 1100X32+ 1500X42+ 1600X52<= 1000000
(3)   500X13+ 1500X23+ 1100X33+ 1500X43+ 1600X53<= 1000000
(4)   500X14+ 1500X24+ 1100X34+ 1500X44+ 1600X54<= 1000000


(5)   1500X11+ 3500X21+ 3800X31+ 7000X41+ 7500X51<= 4000000
(6)   1500X12+ 3500X22+ 3800X32+ 7000X42+ 7500X52<= 4000000
(7)   1500X13+ 3500X23+ 3800X33+ 7000X43+ 7500X53<= 4000000
(8)   1500X14+ 3500X24+ 3800X34+ 7000X44+ 7500X54<= 4000000


(9)   720X11+ 900X21+ 942X31+ 1092X41+ 1170X51<= 800000
(10)  720X12+ 900X22+ 942X32+ 1092X42+ 1170X52<= 800000
(11)  720X13+ 900X23+ 942X33+ 1092X43+ 1170X53<= 800000
(12)  720X14+ 900X24+ 942X34+ 1092X44+ 1170X54<= 800000


(13)  800X11+ 1200X21+ 1320X31+ 1680X41+ 1800X51<= 600000
(14)  800X12+ 1200X22+ 1320X32+ 1680X42+ 1800X52<= 600000
(15)  800X13+ 1200X23+ 1320X33+ 1680X43+ 1800X53<= 600000
(16)  800X14+ 1200X24+ 1320X34+ 1680X44+ 1800X54<= 600000
```

```
(17)  500X11+ 600X21+ 620X31+ 700X41+ 750X51<= 500000
(18)  500X12+ 600X22+ 620X32+ 700X42+ 750X52<= 500000
(19)  500X13+ 600X23+ 620X33+ 700X43+ 750X53<= 500000
(20)  500X14+ 600X24+ 620X34+ 700X44+ 750X54<= 500000


(21)  200X11+ 280X21+ 304X31+ 360X41+ 384X51<= 400000
(22)  200X12+ 280X22+ 304X32+ 360X42+ 384X52<= 400000
(23)  200X13+ 280X23+ 304X33+ 360X43+ 384X53<= 400000
(24)  200X14+ 280X24+ 304X34+ 360X44+ 384X54<= 400000


(25)  150X11+ 240X21+ 270X31+ 345X41+ 375X51<= 300000
(26)  150X12+ 240X22+ 270X32+ 345X42+ 375X52<= 300000
(27)  150X13+ 240X23+ 270X33+ 345X43+ 375X53<= 300000
(28)  150X14+ 240X24+ 270X34+ 345X44+ 375X54<= 300000


(29)  500X11+ 560X21+ 600X31+ 640X41+ 660X51<= 600000
(30)  500X12+ 560X22+ 600X32+ 640X42+ 660X52<= 600000
(31)  500X13+ 560X23+ 600X33+ 640X43+ 660X53<= 600000
(32)  500X14+ 560X24+ 600X34+ 640X44+ 660X54<= 600000


(33)  580X11+ 720X21+ 760X31+ 920X41+ 1000X51<= 800000
(34)  580X12+ 720X22+ 760X32+ 920X42+ 1000X52<= 800000
(35)  580X13+ 720X23+ 760X33+ 920X43+ 1000X53<= 800000
(36)  580X14+ 720X24+ 760X34+ 920X44+ 1000X54<= 800000


(37)  100X11+ 100X21+ 100X31+ 200X41+ 200X51<= 200000
(38)  100X12+ 100X22+ 100X32+ 200X42+ 200X52<= 200000
(39)  100X13+ 100X23+ 100X33+ 200X43+ 200X53<= 200000
(40)  100X14+ 100X24+ 100X34+ 200X44+ 200X54<= 200000


(41)  375X11+ 500X21+ 500X31+ 625X41+ 625X51<= 450000
(42)  375X12+ 500X22+ 500X32+ 625X42+ 625X52<= 450000
(43)  375X13+ 500X23+ 500X33+ 625X43+ 625X53<= 450000
(44)  375X14+ 500X24+ 500X34+ 625X44+ 625X54<= 450000


(45)  80000Z11+ 88000Z21+ 80000Z31+ 92000Z41+ 100000Z51<= 600000
(46)  80000Z12+ 88000Z22+ 80000Z32+ 92000Z42+ 100000Z52<= 600000
(47)  80000Z13+ 88000Z23+ 80000Z33+ 92000Z43+ 100000Z53<= 600000
(48)  80000Z14+ 88000Z24+ 80000Z34+ 92000Z44+ 100000Z54<= 600000
```

```
(49)  150000Z11+ 225000Z21+ 270000Z31+ 330000Z41+ 360000Z51<= 2000000
(50)  150000Z12+ 225000Z22+ 270000Z32+ 330000Z42+ 360000Z52<= 2000000
(51)  150000Z13+ 225000Z23+ 270000Z33+ 330000Z43+ 360000Z53<= 2000000
(52)  150000Z14+ 225000Z24+ 270000Z34+ 330000Z44+ 360000Z54<= 2000000


(53)  X11-999999999Z11<= 0
(54)  X12-999999999Z12<= 0
(55)  X13-999999999Z13<= 0
(56)  X14-999999999Z14<= 0


(57)  X21-999999999Z21<= 0
(58)  X22-999999999Z22<= 0
(59)  X23-999999999Z23<= 0
(60)  X24-999999999Z24<= 0


(61)  X31-999999999Z31<= 0
(62)  X32-999999999Z32<= 0
(63)  X33-999999999Z33<= 0
(64)  X34-999999999Z34<= 0


(65)  X41-999999999Z41<= 0
(66)  X42-999999999Z42<= 0
(67)  X43-999999999Z43<= 0
(68)  X44-999999999Z44<= 0


(69)  X51-999999999Z51<= 0
(70)  X52-999999999Z52<= 0
(71)  X53-999999999Z53<= 0
(72)  X54-999999999Z54<= 0


(73)  X11<= 300
(74)  X12<= 250
(75)  X13<= 330
(76)  X14<= 400


(77)  X21<= 200
(78)  X22<= 130
(79)  X23<= 200
(80)  X24<= 240
```

```
(81)  X31<= 200
(82)  X32<= 150
(83)  X33<= 160
(84)  X34<= 220


(85)  X41<= 120
(86)  X42<= 150
(87)  X43<= 80
(88)  X44<= 50


(89)  X51<= 100
(90)  X52<= 125
(91)  X53<= 50
(92)  X54<= 20

generals

X11
X12
X13
X14
X21
X22
X23
X24
X31
X32
X33
X34
X41
X42
X43
X44
X51
X52
X53
X54

binaries

Z11
Z12
Z13
Z14
Z21
```

```
Z22
Z23
Z24
Z31
Z32
Z33
Z34
Z41
Z42
Z43
Z44
Z51
Z52
Z53
Z54
END
```

Appendix W. The output of the mathematical model developed for the GUROTO Company

```
Integer optimal solution (0.0001/0):  Objective =    7.2035030000e+06
Current MIP best bound =    7.2041523636e+06 (gap = 649.364)
Solution time =    0.00 sec.  Iterations = 401  Nodes = 236 (1)


CPLEX> display sol var –

Variable Name           Solution Value

X13                         330.000000
X14                         387.000000
X23                         104.000000
X31                         168.000000
X32                          93.000000
X33                         160.000000
X34                         220.000000
X41                         118.000000
X42                         150.000000
X51                         100.000000
X52                         125.000000
Z31                           1.000000
Z41                           1.000000
Z51                           1.000000
Z32                           1.000000
Z42                           1.000000
Z52                           1.000000
Z13                           1.000000
Z23                           1.000000
Z33                           1.000000
Z14                           1.000000
Z34                           1.000000

All other variables in the range 1-40 are zero.


Display the values of which slack(s):

CPLEX> dis sol sla –

Constraint Name                 Slack Value

slack c1                     478200.000000
slack c2                     472700.000000
slack c3                     503000.000000
slack c4                     564500.000000
slack c5                    1785600.000000
slack c6                    1659100.000000
slack c7                    2533000.000000
slack c8                    2583500.000000
```

```
slack c9                      395888.000000
slack c10                     402344.000000
slack c11                     318080.000000
slack c12                     314120.000000
slack c14                        240.000000
slack c17                     238240.000000
slack c18                     243590.000000
slack c19                     173400.000000
slack c20                     170100.000000
slack c21                     268048.000000
slack c22                     269728.000000
slack c23                     256240.000000
slack c24                     255720.000000
slack c25                     176430.000000
slack c26                     176265.000000
slack c27                     182340.000000
slack c28                     182550.000000
slack c29                     357680.000000
slack c30                     365700.000000
slack c31                     280760.000000
slack c32                     274500.000000
slack c33                     463760.000000
slack c34                     466320.000000
slack c35                     412120.000000
slack c36                     408340.000000
slack c37                     139600.000000
slack c38                     135700.000000
slack c39                     140600.000000
slack c40                     139300.000000
slack c41                     229750.000000
slack c42                     231625.000000
slack c43                     194250.000000
slack c44                     194875.000000
slack c45                     328000.000000
slack c46                     328000.000000
slack c47                     352000.000000
slack c48                     440000.000000
slack c49                    1040000.000000
slack c50                    1040000.000000
slack c51                    1355000.000000
slack c52                    1580000.000000
slack c55                  999999669.000000
slack c56                  999999612.000000
slack c59                  999999895.000000
slack c61                  999999831.000000
slack c62                  999999906.000000
slack c63                  999999839.000000
slack c64                  999999779.000000
slack c65                  999999881.000000
slack c66                  999999849.000000
slack c69                  999999899.000000
```

```
slack c70                    999999874.000000
slack c73                          300.000000
slack c74                          250.000000
slack c76                           13.000000
slack c77                          200.000000
slack c78                          130.000000
slack c79                           96.000000
slack c80                          240.000000
slack c81                           32.000000
slack c82                           57.000000
slack c85                            2.000000
slack c87                           80.000000
slack c88                           50.000000
slack c91                           50.000000
slack c92                           20.000000

All other slacks in the range 1-92 are zero.
```

VITA

AYSE PINAR GURSES

PERSONAL: Date and Place of Birth: June 1st, 1975, Ankara/Turkey
Nationality: Turkish

EDUCATION: MS, Industrial & Systems Engineering, July 1999
Virginia Polytechnic Institute and State University

BS, Industrial Engineering, July 1997
Orta Dogu Teknik Universitesi, Ankara, Turkey
BS Graduation Project: Design of the Turkish Tractor Factory's inventory layout and determination of the material handling equipment

High school, June 1993
Ankara Ozel Yuce Fen Lisesi

EXPERIENCE: Graduate teaching assistant, Fall-Spring 1998
-Virginia Polytechnic Institute and State University
- Worked for the undergraduate Production Planning and Inventory Control and Industrial Cost Control courses

Engineering Intern, July -August 1996
TAKSAN Machine Tools Industry and Trade Co., Kayseri, Turkey
- Worked in conjunction with professors from the Industrial and Mechanical Engineering Departments of the Orta Dogu Teknik Universitesi on a EUREKA project entitled *REMAPHOS: Restructuring a Large Scale Discrete Manufacturing Plant as a Holonic System*
- Determined the capacity of the plant using a queuing network approach.

Engineering Intern, August-September 1995
Turkish Aerospace Industries (TAI), Ankara, Turkey
- Observed the production of F-16 Fighting Falcon aircraft and analyzed the use of the MRP-II system in the plant

SKILLS: Language- Turkish, English, German

Computer- Turbo PASCAL, FORTRAN, VBA, MS Office, MS Project, SIMAN, various web-page editors