

# Homework Assignment 2 Code

January 28, 2024

```
[1]: #load libraries
from pulp import LpVariable, LpProblem, LpMaximize, LpMinimize, LpStatus, Lp
    value, GLPK
import pulp as pulp
```

## 1 Expected Hours

### 1.0.1 Product Prototype Development

```
[38]: #define variables
d0 = LpVariable("d0", 0, None)
d1 = LpVariable("d1", 0, None)
d2 = LpVariable("d2", 0, None)
d3 = LpVariable("d3", 0, None)
d4 = LpVariable("d4", 0, None)
d5 = LpVariable("d5", 0, None)
d6 = LpVariable("d6", 0, None)
d7 = LpVariable("d7", 0, None)
d8 = LpVariable("d8", 0, None)

#define the problem that minimizes completion time
probp = LpProblem("problem", LpMinimize)

#define constraints
probp += d0*(-1) + d1*1 >= 16
probp += d1*(-1) + d2*1 >= 120
probp += d1*(-1) + d3*1 >= 40
probp += d2*1 + d3*(-1) >= 0
probp += d2*(-1) + d4*1 >= 80
probp += d4*(-1) + d5*1 >= 40
probp += d4*(-1) + d6*1 >= 40
probp += d6*(-1) + d7*1 >= 40
probp += d5*1 + d7*(-1) >= 0
probp += d5*(-1) + d8*1 >= 40

#define objective function
```

```

probp += d8 - d0

#solve problem
probp.writeLP("probp.lp")
probp.solve(GLPK(msg=True, options=['--ranges', 'sensitivity_exp_p.txt']))
print("Status:", LpStatus[probp.status])

probp_results = []

for v in probp.variables():
    print(v.name, "=", v.varValue)
    probp_results.append(v.varValue)

print("Objective", value(probp.objective))
print("")

```

```

GLPSOL--GLPK LP/MIP Solver 5.0
Parameter(s) specified in the command line:
--cpxlp /var/folders/z0/v3y1p30945d16_whz3lt8v_h0000gn/T/ed43016dcda84fc4a4e8fb
5040cf9874-pulp.lp
-o /var/folders/z0/v3y1p30945d16_whz3lt8v_h0000gn/T/ed43016dcda84fc4a4e8fb5040c
f9874-pulp.sol
--ranges sensitivity_exp_p.txt
Reading problem data from '/var/folders/z0/v3y1p30945d16_whz3lt8v_h0000gn/T/ed43
016dcda84fc4a4e8fb5040cf9874-pulp.lp'...
10 rows, 9 columns, 20 non-zeros
15 lines were read
GLPK Simplex Optimizer 5.0
10 rows, 9 columns, 20 non-zeros
Preprocessing...
9 rows, 8 columns, 18 non-zeros
Scaling...
A: min|aij| = 1.000e+00 max|aij| = 1.000e+00 ratio = 1.000e+00
Problem data seem to be well scaled
Constructing initial basis...
Size of triangular part is 9
      0: obj = 4.000000000e+01 inf = 3.760e+02 (7)
      9: obj = 3.360000000e+02 inf = 0.000e+00 (0)
OPTIMAL LP SOLUTION FOUND
Time used: 0.0 secs
Memory used: 0.0 Mb (42553 bytes)
Writing basic solution to '/var/folders/z0/v3y1p30945d16_whz3lt8v_h0000gn/T/ed43
016dcda84fc4a4e8fb5040cf9874-pulp.sol'...
Write sensitivity analysis report to 'sensitivity_exp_p.txt'...
Status: Optimal
d0 = 0.0
d1 = 16.0
d2 = 136.0

```

```
d3 = 56.0
d4 = 216.0
d5 = 296.0
d6 = 256.0
d7 = 296.0
d8 = 336.0
Objective 336.0
```

```
[39]: prototype = probp_results[8]
      prototype
```

```
[39]: 336.0
```

## 1.0.2 Recommendation System Development

```
[40]: #define variables
t0 = LpVariable("t0", 0, None)
t1 = LpVariable("t1", 0, None)
t2 = LpVariable("t2", 0, None)
t3 = LpVariable("t3", 0, None)
t4 = LpVariable("t4", 0, None)
t5 = LpVariable("t5", 0, None)
t6 = LpVariable("t6", 0, None)
t7 = LpVariable("t7", 0, None)
t8 = LpVariable("t8", 0, None)
t9 = LpVariable("t9", 0, None)

#define the problem that minimizes completion time
probr = LpProblem("problem", LpMinimize)

#define constraints
probr += t0*(-1) + t1*1 >= 8
probr += t0*(-1) + t2*1 >= 40
probr += t1*(-1) + t4*1 >= prototype_exp
probr += t1*(-1) + t3*1 >= 40
probr += t2*(-1) + t3*1 >= 0
probr += t4*(-1) + t8*1 >= 0
probr += t4*(-1) + t5*1 >= 0
probr += t3*(-1) + t5*1 >= 40
probr += t5*(-1) + t6*1 >= 24
probr += t7*1 + t8*(-1) >= 24
probr += t6*(-1) + t7*1 >= 0
probr += t1*(-1) + t8*1 >= 0
probr += t7*(-1) + t9*1 >= 40

#define objective function
probr += t9 - t0
```

```

#solve problem
probr.writeLP("probr.lp")
probr.solve(GLPK(msg=True, options=['--ranges', 'sensitivity_exp_r.txt']))
print("Status:", LpStatus[probr.status])

for v in probr.variables():
    print(v.name, "=", v.varValue)

print("Objective", value(probr.objective))
print("")

```

```

GLPSOL--GLPK LP/MIP Solver 5.0
Parameter(s) specified in the command line:
  --cpxlp /var/folders/z0/v3y1p30945d16_whz3lt8v_h0000gn/T/c7f0f12089bd451cb100dd
3e3b17b2c6-pulp.lp
  -o /var/folders/z0/v3y1p30945d16_whz3lt8v_h0000gn/T/c7f0f12089bd451cb100dd3e3b1
7b2c6-pulp.sol
  --ranges sensitivity_exp_r.txt
Reading problem data from '/var/folders/z0/v3y1p30945d16_whz3lt8v_h0000gn/T/c7f0
f12089bd451cb100dd3e3b17b2c6-pulp.lp'...
13 rows, 10 columns, 26 non-zeros
18 lines were read
GLPK Simplex Optimizer 5.0
13 rows, 10 columns, 26 non-zeros
Preprocessing...
12 rows, 9 columns, 24 non-zeros
Scaling...
  A: min|aij| = 1.000e+00  max|aij| = 1.000e+00  ratio = 1.000e+00
Problem data seem to be well scaled
Constructing initial basis...
Size of triangular part is 12
      0: obj = 4.000000000e+01 inf = 5.120e+02 (7)
     11: obj = 4.080000000e+02 inf = 0.000e+00 (0)
OPTIMAL LP SOLUTION FOUND
Time used: 0.0 secs
Memory used: 0.0 Mb (44065 bytes)
Writing basic solution to '/var/folders/z0/v3y1p30945d16_whz3lt8v_h0000gn/T/c7f0
f12089bd451cb100dd3e3b17b2c6-pulp.sol'...
Write sensitivity analysis report to 'sensitivity_exp_r.txt'...
Status: Optimal
t0 = 0.0
t1 = 8.0
t2 = 40.0
t3 = 48.0
t4 = 344.0
t5 = 344.0
t6 = 368.0

```

```
t7 = 368.0
t8 = 344.0
t9 = 408.0
Objective 408.0
```

## 2 Best Case Hours

### 2.0.1 Product Prototype Development

```
[41]: #define variables
d0 = LpVariable("d0", 0, None)
d1 = LpVariable("d1", 0, None)
d2 = LpVariable("d2", 0, None)
d3 = LpVariable("d3", 0, None)
d4 = LpVariable("d4", 0, None)
d5 = LpVariable("d5", 0, None)
d6 = LpVariable("d6", 0, None)
d7 = LpVariable("d7", 0, None)
d8 = LpVariable("d8", 0, None)

#define the problem that minimizes completion time
probp = LpProblem("problem", LpMinimize)

#define constraints
probp += d0*(-1) + d1*1 >= 14.4
probp += d1*(-1) + d2*1 >= 108
probp += d1*(-1) + d3*1 >= 36
probp += d2*1 + d3*(-1) >= 0
probp += d2*(-1) + d4*1 >= 72
probp += d4*(-1) + d5*1 >= 36
probp += d4*(-1) + d6*1 >= 36
probp += d6*(-1) + d7*1 >= 36
probp += d5*1 + d7*(-1) >= 0
probp += d5*(-1) + d8*1 >= 36

#define objective function
probp += d8 - d0

#solve problem
probp.writeLP("probp.lp")
probp.solve(GLPK(msg=True, options=['--ranges', 'sensitivity_best_p.txt']))
print("Status:", LpStatus[probp.status])

probp_results = []
```

```

for v in probp.variables():
    print(v.name, "=", v.varValue)
    probp_results.append(v.varValue)

print("Objective", value(probp.objective))
print("")

```

```

GLPSOL--GLPK LP/MIP Solver 5.0
Parameter(s) specified in the command line:
  --cpxlp /var/folders/z0/v3y1p30945d16_whz3lt8v_h0000gn/T/a2a4ac7883bb4811805bfa
a2fd61e75c-pulp.lp
  -o /var/folders/z0/v3y1p30945d16_whz3lt8v_h0000gn/T/a2a4ac7883bb4811805bfaa2fd6
1e75c-pulp.sol
  --ranges sensitivity_best_p.txt
Reading problem data from '/var/folders/z0/v3y1p30945d16_whz3lt8v_h0000gn/T/a2a4
ac7883bb4811805bfaa2fd61e75c-pulp.lp'...
10 rows, 9 columns, 20 non-zeros
15 lines were read
GLPK Simplex Optimizer 5.0
10 rows, 9 columns, 20 non-zeros
Preprocessing...
9 rows, 8 columns, 18 non-zeros
Scaling...
  A: min|aij| = 1.000e+00  max|aij| = 1.000e+00  ratio = 1.000e+00
Problem data seem to be well scaled
Constructing initial basis...
Size of triangular part is 9
      0: obj = 3.600000000e+01 inf = 3.384e+02 (7)
      9: obj = 3.024000000e+02 inf = 0.000e+00 (0)
OPTIMAL LP SOLUTION FOUND
Time used: 0.0 secs
Memory used: 0.0 Mb (42553 bytes)
Writing basic solution to '/var/folders/z0/v3y1p30945d16_whz3lt8v_h0000gn/T/a2a4
ac7883bb4811805bfaa2fd61e75c-pulp.sol'...
Write sensitivity analysis report to 'sensitivity_best_p.txt'...
Status: Optimal
d0 = 0.0
d1 = 14.4
d2 = 122.4
d3 = 50.4
d4 = 194.4
d5 = 266.4
d6 = 230.4
d7 = 266.4
d8 = 302.4
Objective 302.4

```

```
[44]: prototype = probp_results[8]
      prototype
```

```
[44]: 302.4
```

## 2.0.2 Recommendation System Development

```
[45]: #define variables
t0 = LpVariable("t0", 0, None)
t1 = LpVariable("t1", 0, None)
t2 = LpVariable("t2", 0, None)
t3 = LpVariable("t3", 0, None)
t4 = LpVariable("t4", 0, None)
t5 = LpVariable("t5", 0, None)
t6 = LpVariable("t6", 0, None)
t7 = LpVariable("t7", 0, None)
t8 = LpVariable("t8", 0, None)
t9 = LpVariable("t9", 0, None)

#define the problem that minimizes completion time
probr = LpProblem("problem", LpMinimize)

#define constraints
probr += t0*(-1) + t1*1 >= 7.2
probr += t0*(-1) + t2*1 >= 36
probr += t1*(-1) + t4*1 >= prototype
probr += t1*(-1) + t3*1 >= 36
probr += t2*(-1) + t3*1 >= 0
probr += t4*(-1) + t8*1 >= 0
probr += t4*(-1) + t5*1 >= 0
probr += t3*(-1) + t5*1 >= 36
probr += t5*(-1) + t6*1 >= 21.6
probr += t7*1 + t8*(-1) >= 21.6
probr += t6*(-1) + t7*1 >= 0
probr += t1*(-1) + t8*1 >= 0
probr += t7*(-1) + t9*1 >= 36

#define objective function
probr += t9 - t0

#solve problem
probr.writeLP("probr.lp")
probr.solve(GLPK(msg=True, options=['--ranges', 'sensitivity_best_r.txt']))
print("Status:", LpStatus[probr.status])

for v in probr.variables():
    print(v.name, "=", v.varValue)
```

```
print("Objective", value(probr.objective))
print("")
```

```
GLPSOL--GLPK LP/MIP Solver 5.0
Parameter(s) specified in the command line:
  --cpxlp /var/folders/z0/v3y1p30945d16_whz3lt8v_h0000gn/T/21f1161381d144649aa8c5
4976313a22-pulp.lp
  -o /var/folders/z0/v3y1p30945d16_whz3lt8v_h0000gn/T/21f1161381d144649aa8c549763
13a22-pulp.sol
  --ranges sensitivity_best_r.txt
Reading problem data from '/var/folders/z0/v3y1p30945d16_whz3lt8v_h0000gn/T/21f1
161381d144649aa8c54976313a22-pulp.lp'...
13 rows, 10 columns, 26 non-zeros
18 lines were read
GLPK Simplex Optimizer 5.0
13 rows, 10 columns, 26 non-zeros
Preprocessing...
12 rows, 9 columns, 24 non-zeros
Scaling...
  A: min|aij| = 1.000e+00  max|aij| = 1.000e+00  ratio = 1.000e+00
Problem data seem to be well scaled
Constructing initial basis...
Size of triangular part is 12
      0: obj = 3.600000000e+01  inf = 4.608e+02 (7)
     11: obj = 3.672000000e+02  inf = 0.000e+00 (0)
OPTIMAL LP SOLUTION FOUND
Time used: 0.0 secs
Memory used: 0.0 Mb (44065 bytes)
Writing basic solution to '/var/folders/z0/v3y1p30945d16_whz3lt8v_h0000gn/T/21f1
161381d144649aa8c54976313a22-pulp.sol'...
Write sensitivity analysis report to 'sensitivity_best_r.txt'...
Status: Optimal
t0 = 0.0
t1 = 7.2
t2 = 36.0
t3 = 43.2
t4 = 309.6
t5 = 309.6
t6 = 331.2
t7 = 331.2
t8 = 309.6
t9 = 367.2
Objective 367.2
```



## 3 Worst Case Hours

### 3.0.1 Product Prototype Development

```
[46]: #define variables
d0 = LpVariable("d0", 0, None)
d1 = LpVariable("d1", 0, None)
d2 = LpVariable("d2", 0, None)
d3 = LpVariable("d3", 0, None)
d4 = LpVariable("d4", 0, None)
d5 = LpVariable("d5", 0, None)
d6 = LpVariable("d6", 0, None)
d7 = LpVariable("d7", 0, None)
d8 = LpVariable("d8", 0, None)

#define the problem that minimizes completion time
probp = LpProblem("problem", LpMinimize)

#define constraints
probp += d0*(-1) + d1*1 >= 17.6
probp += d1*(-1) + d2*1 >= 132
probp += d1*(-1) + d3*1 >= 44
probp += d2*1 + d3*(-1) >= 0
probp += d2*(-1) + d4*1 >= 88
probp += d4*(-1) + d5*1 >= 44
probp += d4*(-1) + d6*1 >= 44
probp += d6*(-1) + d7*1 >= 44
probp += d5*1 + d7*(-1) >= 0
probp += d5*(-1) + d8*1 >= 44

#define objective function
probp += d8 - d0

#solve problem
probp.writeLP("probp.lp")
probp.solve(GLPK(msg=True, options=['--ranges', 'sensitivity_worst_p.txt']))
print("Status:", LpStatus[probp.status])

probp_results = []

for v in probp.variables():
    print(v.name, "=", v.varValue)
    probp_results.append(v.varValue)

print("Objective", value(probp.objective))
print("")
```

```

GLPSOL--GLPK LP/MIP Solver 5.0
Parameter(s) specified in the command line:
  --cpxlp /var/folders/z0/v3y1p30945d16_whz3lt8v_h0000gn/T/37527240ab18479b945d97
0cf29f25a5-pulp.lp
  -o /var/folders/z0/v3y1p30945d16_whz3lt8v_h0000gn/T/37527240ab18479b945d970cf29
f25a5-pulp.sol
  --ranges sensitivity_worst_p.txt
Reading problem data from '/var/folders/z0/v3y1p30945d16_whz3lt8v_h0000gn/T/3752
7240ab18479b945d970cf29f25a5-pulp.lp'...
10 rows, 9 columns, 20 non-zeros
15 lines were read
GLPK Simplex Optimizer 5.0
10 rows, 9 columns, 20 non-zeros
Preprocessing...
9 rows, 8 columns, 18 non-zeros
Scaling...
  A: min|aij| = 1.000e+00  max|aij| = 1.000e+00  ratio = 1.000e+00
Problem data seem to be well scaled
Constructing initial basis...
Size of triangular part is 9
      0: obj = 4.400000000e+01  inf = 4.136e+02 (7)
      9: obj = 3.696000000e+02  inf = 0.000e+00 (0)
OPTIMAL LP SOLUTION FOUND
Time used: 0.0 secs
Memory used: 0.0 Mb (42553 bytes)
Writing basic solution to '/var/folders/z0/v3y1p30945d16_whz3lt8v_h0000gn/T/3752
7240ab18479b945d970cf29f25a5-pulp.sol'...
Write sensitivity analysis report to 'sensitivity_worst_p.txt'...
Status: Optimal
d0 = 0.0
d1 = 17.6
d2 = 149.6
d3 = 61.6
d4 = 237.6
d5 = 325.6
d6 = 281.6
d7 = 325.6
d8 = 369.6
Objective 369.6

```

```
[47]: prototype = probp_results[8]
      prototype
```

```
[47]: 369.6
```

### 3.0.2 Recommendation System Development

```
[48]: #define variables
t0 = LpVariable("t0", 0, None)
t1 = LpVariable("t1", 0, None)
t2 = LpVariable("t2", 0, None)
t3 = LpVariable("t3", 0, None)
t4 = LpVariable("t4", 0, None)
t5 = LpVariable("t5", 0, None)
t6 = LpVariable("t6", 0, None)
t7 = LpVariable("t7", 0, None)
t8 = LpVariable("t8", 0, None)
t9 = LpVariable("t9", 0, None)

#define the problem that minimizes completion time
probr = LpProblem("problem", LpMinimize)

#define constraints
probr += t0*(-1) + t1*1 >= 8.8
probr += t0*(-1) + t2*1 >= 44
probr += t1*(-1) + t4*1 >= prototype
probr += t1*(-1) + t3*1 >= 44
probr += t2*(-1) + t3*1 >= 0
probr += t4*(-1) + t8*1 >= 0
probr += t4*(-1) + t5*1 >= 0
probr += t3*(-1) + t5*1 >= 44
probr += t5*(-1) + t6*1 >= 26.4
probr += t7*1 + t8*(-1) >= 26.4
probr += t6*(-1) + t7*1 >= 0
probr += t1*(-1) + t8*1 >= 0
probr += t7*(-1) + t9*1 >= 44

#define objective function
probr += t9 - t0

#solve problem
probr.writeLP("probr.lp")
probr.solve(GLPK(msg=True, options=['--ranges', 'sensitivity_worst_r.txt']))
print("Status:", LpStatus[probr.status])

for v in probr.variables():
    print(v.name, "=", v.varValue)

print("Objective", value(probr.objective))
print("")
```

GLPSOL--GLPK LP/MIP Solver 5.0

Parameter(s) specified in the command line:

```

--cpxlp /var/folders/z0/v3y1p30945d16_whz3lt8v_h0000gn/T/07efb489164c41a691c036
a0ceb7b202-pulp.lp
-o /var/folders/z0/v3y1p30945d16_whz3lt8v_h0000gn/T/07efb489164c41a691c036a0ceb
7b202-pulp.sol
--ranges sensitivity_worst_r.txt
Reading problem data from '/var/folders/z0/v3y1p30945d16_whz3lt8v_h0000gn/T/07ef
b489164c41a691c036a0ceb7b202-pulp.lp'...
13 rows, 10 columns, 26 non-zeros
18 lines were read
GLPK Simplex Optimizer 5.0
13 rows, 10 columns, 26 non-zeros
Preprocessing...
12 rows, 9 columns, 24 non-zeros
Scaling...
A: min|aij| = 1.000e+00 max|aij| = 1.000e+00 ratio = 1.000e+00
Problem data seem to be well scaled
Constructing initial basis...
Size of triangular part is 12
      0: obj = 4.400000000e+01 inf = 5.632e+02 (7)
     11: obj = 4.488000000e+02 inf = 0.000e+00 (0)
OPTIMAL LP SOLUTION FOUND
Time used: 0.0 secs
Memory used: 0.0 Mb (44065 bytes)
Writing basic solution to '/var/folders/z0/v3y1p30945d16_whz3lt8v_h0000gn/T/07ef
b489164c41a691c036a0ceb7b202-pulp.sol'...
Write sensitivity analysis report to 'sensitivity_worst_r.txt'...
Status: Optimal
t0 = 0.0
t1 = 8.8
t2 = 44.0
t3 = 52.8
t4 = 378.4
t5 = 378.4
t6 = 404.8
t7 = 404.8
t8 = 378.4
t9 = 448.8
Objective 448.8

```