WQD7011 NUMERICAL OPTIMIZATION
GROUP PROJECT
The Triad

"OPTIMIZING THE MANUFACTURING PROCESS IN A FURNITURE FACTORY"

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Introduction

Business requires an improved process in order to maintain its competitiveness and increase its financial performance to the desired level. These objectives in the end result most of enterprises to perform multiple activities that are innovative and creative for them to take care of not only the outputs, but also the processes. In other words, efficiency and effectiveness are the keys towards finding an optimization in certain processes. Pertaining to the title of this project, we managed to find a real life problem which can be encountered in a furniture factory that wants to reduce the cost of its manufacturing operation while still maintaining the finishing quality and required volume output of its product, in order to remain competitive in the furniture market.

We decided to start by focusing on one particular machine known as a CNC (computer numerical control) milling machine as shown in the picture below. This machine uses the computer control to guide its tool in the cutting and milling of the raw material into precision parts that will be used in the final product.

The advantage of a CNC machine is that it can automatically respond to the input of parameters and also record the parameters that will be used for the data collection.
It can manipulate its cutting speed and its feed rate to produce maxima effectiveness of sub-process. Our target is to find out the solution that minimize cost and maximize efficiency while maintaining product quality to an acceptable level.

Significance of this calculation

Finding the optimal solution while maintaining the required product quality lies in the reduction of important factors of the manufacturing process .The change of the variables in the optimization problem design shall result in a reduction of production costs, operation time and at the end, in the minimization of the optimization task.

Variables and data

We have identified three independent variables to be used for the numerical modelling, volume of the removed material ,V; cutting speed of the machine , v_c; and feed rate of the raw material, v_f.

Independent variable:
Cutting speed, v_c $(m \cdot min^{-1})$
Feed rate, v_f $(m \cdot min^{-1})$
Volume removal, V (cm^3)

We then identified, the dependent variables, the production cost, N_o; process duration, T_s; and surface roughness (a measure of the product quality), R_a.
Dependent variable:
Production cost, N_o(EUR)
Process duration, T_s (min)
Surface roughness, R_a (mm)
From the dependent variables, the Production Cost, N_o, will be the objective function while the constraints are Process Duration, T_s and Surface Roughness, R_a.

The next step will be to model the linear equations for all three dependent variables. We began by obtaining data from the measured and calculated output parameters. These are the data collected with test samples being experimented on with different input parameters (independent variables), with the output parameters recorded and calculated.
The data collected are then compiled into csv format to be ready for the next step.

Table 1 Output of test samples for Production Cost

vc	vf	V	No
2513.27	4	101.89	3.08
3141.59	4	203.78	4.79
3769.91	4	305.67	6.92
4398.23	4	407.56	9.48
2513.27	8	509.45	1.61
3141.59	8	611.34	2.46
3769.91	8	713.23	3.53
4398.23	8	815.12	4.81
2513.27	10	917.01	1.31
3141.59	10	1018.9	1.99
3769.91	10	1120.79	2.85
4398.23	10	1222.68	3.87
1884.96	4	1324.57	1.8
1884.96	8	1426.46	0.96
1884.96	10	1528.35	0.8
4084.07	4	1630.24	8.14
4084.07	8	1732.13	4.14
4084.07	10	1834.02	3.34

Table 2 Output of test samples on Surface Roughness

vc	vf	V	Ra
2513.27	4	101.89	0.011496
3141.59	4	203.78	0.01077
3769.91	4	305.67	0.011861
4398.23	4	407.56	0.012719
2513.27	8	509.45	0.01438
3141.59	8	611.34	0.014243
3769.91	8	713.23	0.012599
4398.23	8	815.12	0.012209
2513.27	10	917.01	0.014933
3141.59	10	1018.9	0.013401
3769.91	10	1120.79	0.010359
4398.23	10	1222.68	0.011405
1884.96	4	1324.57	0.01185
1884.96	8	1426.46	0.012937
1884.96	10	1528.35	0.013171
4084.07	4	1630.24	0.010667
4084.07	8	1732.13	0.01055
4084.07	10	1834.02	0.011218

Table 3 Output of test samples on Process Duration

vc	vf	V	Ts
2513.27	4	101.89	0.517
3141.59	4	203.78	0.517
3769.91	4	305.67	0.517
4398.23	4	407.56	0.517
2513.27	8	509.45	0.392
3141.59	8	611.34	0.392
3769.91	8	713.23	0.392
4398.23	8	815.12	0.392
2513.27	10	917.01	0.367
3141.59	10	1018.9	0.367
3769.91	10	1120.79	0.367
4398.23	10	1222.68	0.367
1884.96	4	1324.57	0.517
1884.96	8	1426.46	0.392
1884.96	10	1528.35	0.376
4084.07	4	1630.24	0.517
4084.07	8	1732.13	0.392
4084.07	10	1834.02	0.367

Modelling the data

The datasets are then modelled using *linear multivariate regression* method to create a linear equations of the dependent variables. The Octave program is used to assist us in the calculation, datasets are imported and the Normal Equation method is used to calculate the corresponding coefficients for the equations' variables(θ).

```
%generate theta for No (total cost)

data = csvread('no.csv')
%data = csvread('ra.csv')
%data = csvread('ts.csv')

x = data (:,1:3);
y = data (:,4);

m=length(x);
X=[ones(m,1) x];

theta = (pinv(X'*X))*X'*y

fprintf('Theta for No (Total cost)\n');
```

Figure 1 Program to calculate the coefficients of the variables

```
theta =

   1.44435561
   0.00193794
  -0.59774284
   0.00021330

Theta for No (Total cost)
>>
```

Figure 2 Output for Total Cost

```
theta =

   0.61651033271
  -0.00000095975
  -0.02599559251
   0.00000322664

Theta for Ts (process time)
>>
```

Figure 3 Output for Process Duration

```
theta =

   0.01359815884
  -0.00000068420
   0.00028638775
  -0.00000121543

>> fprintf('Theta for Ra (Surface roughness)\n');

Theta for Ra (Surface roughness)
>> |
```

Figure 4 Output for Surface Roughness

From the models we were able to obtain the coefficients of the linear equations for the dependent variables(θ),

Objective function :

$$N_o = 1.44435561 \; + 0.00193794x_1 \; - 0.59774284x_2 + 0.00021330x_3$$

Subject to:

Constraint 1 :

$$T_s \; = \; -0.00000095795x_1 - 0.0259959251x_2 + 0.00000322664x_3 \; < \; -0.13651$$

Constraint 2:

$$R_a = \; -0.00000068420x_1 - 0.00028638775x_2 - 0.00000121543x_3 < -0.00205996024$$

Of which,
$X_1 = v_c$
$X_2 = v_f$
$X_3 = V$

Linear Programming

After the linear equations were modelled, we then proceed to using Linear Programming as an optimization method to find the optimized parameters for the variables. We used the Simplex Method that is built into the Octave program to find the optimized parameters of the variables.

Slight adjustments were made on the equations in order to fit it into the programs, these adjustments will be resolved later.

The minimum lower boundaries of the variables are set according to the minimum values found in the data set.

```
C=[0.00193794; -0.59774284; 0.0002133];
A = [-0.00000095975 -0.02599559251 0.00000322664;
 -0.0000006842 0.00028638775 -0.00000121543];
b = [-0.13651; -0.00205996024];
lb = [1885; 4; 101];
ub = [4398.23, 10, 1834.02];


cType = 'UU';
varType = 'CCC';
sense = 1;

[xmin, fmin, status, extra] = glpk (C, A, b, lb, ub, cType, varType, sense);
```

Figure 5 Built-in Simplex Method program in Octave

```
>> fmin
fmin =  1.0655
>>
```

Figure 6 Output parameter

From the output, we found the optimized solution for the variables and result,

$x_1 = v_c = 2014.9321\ m \cdot min^{-1}$
$x_2 = v_f = 5.4045\ m \cdot min^{-1}$
$x_3 = V = 1834.0200\ cm^3$

Product cost
N_o = 1.0655+ 1.44435561
= 2.5099EUR

While surface roughness is maintained at
R_a = 0.011538

And operation duration will at level of
T_s = 0.48 min

Discussion

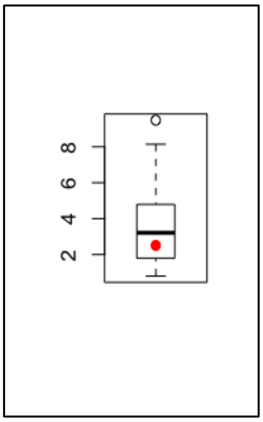

Figure 7 :Lowest product cost

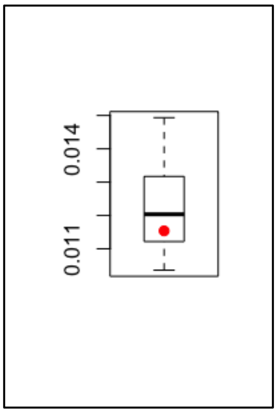

Figure 8 :Surface roughness

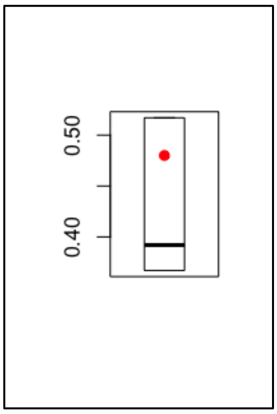

Figure 9 :Process duration

As we can see from boxplot above, when we are putting more weightage on product cost and surface roughness, we can achieve value that are lower than median value from sample data but process duration that are higher than median level.

Advance stage
Thus far the focus has been on reducing cost while maintaining acceptable surface roughness (product quality) and process duration. However, should a decision be made to prioritize on high product quality while allowing the product cost and process duration to increase to a higher threshold, we can do so by making adjustment on the model.

The objective function will be switched to the surface roughness equation, Ra, while product cost No will be a constrain along with process duration Ts.

We then set a higher allowable threshold for both constrains to find the optimized surface roughness (product quality).

Objective function:

$$R_a = 0.01359815884 - 0.00000068420x_1 - 0.00028638775x_2 - 0.00000121543x_3$$

We increase the threshold of the constraints as follows,

Ts <= 0.8min
No <= 5EUR

Upon adjustment of the equation in order to fit into the program, the constraints are as follows,

Constraint 1

$$T_s = -0.00000095795x_1 - 0.0259959251x_2 + 0.00000322664x_3 < 0.183489667$$

Constraint 2

$$N_o = 0.00193794x_1 - 0.59774284x_2 + 0.00021330x_3 < 3.55564439$$

The program is then adjusted and run,

```
C=[-0.0000006842; 0.00028638775; -0.00000121543];
A = [-0.00000095975 -0.02599559251 0.00000322664;
 0.00193794 -0.59774284 0.00000322664];
b = [0.183489667; 3.55564439];
lb = [1885; 4; 101];
ub = [4398.23, 10, 1834.02];


cType = 'UU';
varType = 'CCC';
sense = 1;

[xmin, fmin, status, extra] = glpk (C, A, b, lb, ub, cType, varType, sense);
```

Figure 10 Input parameter for

```
>> fmin
fmin = -0.0031810
>> |
```

Figure 11 Output parameter

The output for the updated surface roughness is as follows,

Ra = 0.01359815884 – 0.003181
= 0.010417158mm

Compared to the previous surface roughness of Ra = 0.011538mm, this however leads to a very minor improvement.

Before	After	Remark
Ts<=0.48min	Ts <= 0.8min	Increase in process duration by 83%.
No <= 2.5099EUR	No <= 5EUR	Increase in product cost by 99%
Ra = 0.011538mm	Ra = 0.010417158mm	Reduction in surface roughness index by 9.7%. Which means an increase in index quality by 9.7%.

Looking at the results, we can see that increasing the process duration by 83% and the product cost by 99% only leads to an improvement in quality of 9.7%.

This shows that the meagre improvement in product quality does not justify they cost it would take on the manufacturer.

Appendix

References

[1] K. M. S. H. Andrea Sujova, "Sustainable Optimization of Manufacturing Effectiveness in Furniture Production," *MDP1,* 2017.

Datasets

vc	vf	V	Ra	No	Ts
2513.27	4	101.89	0.011496	3.08	0.517
3141.59	4	203.78	0.01077	4.79	0.517
3769.91	4	305.67	0.11861	6.92	0.517
4398.23	4	407.56	0.012719	9.48	0.517
2513.27	8	509.45	0.01438	1.61	0.392
3141.59	8	611.34	0.014243	2.46	0.392
3769.91	8	713.23	0.012599	3.53	0.392
4398.23	8	815.12	0.012209	4.81	0.392
2513.27	10	917.01	0.014933	1.31	0.367
3141.59	10	1018.9	0.013401	1.99	0.367
3769.91	10	1120.79	0.010359	2.85	0.367
4398.23	10	1222.68	0.011405	3.87	0.367
1884.96	4	1324.57	0.01185	1.8	0.517
1884.96	8	1426.46	0.012937	0.96	0.392
1884.96	10	1528.35	0.013171	0.8	0.376
4084.07	4	1630.24	0.010667	8.14	0.517
4084.07	8	1732.13	0.01055	4.14	0.392
4084.07	10	1834.02	0.011218	3.34	0.367

Octave code:

```
%generate theta for No (total cost)

data = csvread('no.csv')
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y = data (:,4);

m=length(x);
X=[ones(m,1) x];

theta = (pinv(X'*X))*X'*y

fprintf('Theta for No (Total cost)\n');
```

```
%generate theta for No (total cost)

data = csvread('no.csv')
%data = csvread('ra.csv')
%data = csvread('ts.csv')

x = data (:,1:3);
y = data (:,4);

m=length(x);
X=[ones(m,1) x];

theta = (pinv(X'*X))*X'*y

fprintf('Theta for No (Total cost)\n');



%generate theta for Ts (process time)

%data = csvread('no.csv')
%data = csvread('ra.csv')
data = csvread('ts.csv')

x = data (:,1:3);
y = data (:,4);

m=length(x);
X=[ones(m,1) x];

theta = (pinv(X'*X))*X'*y

fprintf('Theta for Ts (process time)\n');
```

Simplex Method code,

```
C=[0.00193794; -0.59774284; 0.0002133];
A = [-0.00000095975 -0.02599559251 0.00000322664;
 -0.0000006842 0.00028638775 -0.00000121543];
b = [-0.13651; -0.00205996024];
lb = [1885; 4; 101];
ub = [4398.23, 10, 1834.02];


cType = 'UU';
varType = 'CCC';
sense = 1;

[xmin, fmin, status, extra] = glpk (C, A, b, lb, ub, cType, varType, sense);
```

Advance stage code,

```
C=[-0.0000006842; 0.00028638775; -0.00000121543];
A = [-0.00000095975 -0.02599559251 0.00000322664;
 0.00193794 -0.59774284 0.00000322664];
b = [0.183489667; 3.55564439];
lb = [1885; 4; 101];
ub = [4398.23, 10, 1834.02];


cType = 'UU';
varType = 'CCC';
sense = 1;

[xmin, fmin, status, extra] = glpk (C, A, b, lb, ub, cType, varType, sense);
```