

# CHAPTER 5

## RESULTS & DISCUSSIONS

### 5.1 Introduction

The objective of this chapter is to test the possibility of the model in applying to the particular situation. In order to solving the mathematical programming, the LINDO (Linear, INteractive, and Discrete Optimizer) is used as a powerful tool for solving linear, integer, and quadratic programming problems. In this study, the proposed model is indicated as integer programming model. By using LINDO, the program listing, report solution and report after solve the model are shown in Appendix A and Table B-2 of Appendix B.

### 5.2 Testing the Model with Assuming Data

#### 5.2.1 Testing without the space factor

First, we want to test the accurate of the model by assuming the data of few operations. Note that we ignore the space factor for the first time because it is easy to understand. For example:

**Table 5.1: Example Data**

OPN.1	OPN.2	OPN.3	OPN.4
$a_1 = 6.11$	$a_2 = 8.67$	$a_3 = 7.79$	$a_4 = 19.30$
$b_1 = 0$	$b_2 = 0$	$b_3 = 18.65$	$b_4 = 8.92$
$a_1 + b_1 = 6.11$	$a_2 + b_2 = 8.67$	$a_3 + b_3 = 26.44$	$a_4 + b_4 = 28.22$
$1 \leq x_1 \leq 7$	$1 \leq x_2 \leq 4$	$1 \leq x_3 \leq 7$	$1 \leq x_4 \leq 7$
$0 \leq m_1 \leq 5$	$0 \leq m_2 \leq 5$	$1 \leq m_3 \leq 6$	$1 \leq m_4 \leq 7$

Note: OPN. = Operation

## 1. Calculation by hand

The calculation by hand has been done by using the same concept and variables of the proposed model. The objective is to maximize final output when the final output is the minimum number of the maximum output of each operation. It is easier to transform this concept into equation form.

### *Concept*

Objective: Maximize Final Output ( $d_i$ )

Subject to:

$$d_{i+1} \leq d_i \quad i = 1, 2, 3$$

$$d_{i, \max} = \max \left[ \frac{\text{total operating time}_i}{\text{cycle time}_i} \times \text{number of tooling}_i \right]$$

$$m_i \leq \left( \frac{a_i + b_i}{a_i} \right) \times x_{i, \max}$$

$$0 \leq x_i \leq \text{number of operators available at operation } i$$

$$\sum_{i=1}^n x_i \leq \text{Total operators available}$$

$$0 \leq m_i \leq \text{number of tooling available at each operation}$$

Assume: % allowance at each operation = 15%

% Yield at each operation = 90%

% Efficiency at each operation = 95%

% Sampling at each operation = 100%

Therefore,

$$d_{i, \max} = \max \left[ \frac{3600 \times (1 - 15\%) \times 21}{\text{cycle time}_i} \times \frac{90\% \times 95\%}{100\%} \times \text{number of tooling}_i \right]$$

$$d_{i, \max} = \max \left[ \frac{54942.3}{a_i + b_i} \times m_i \right] \text{ at each operation}$$

**At OPN. 1**

$$d_{1 \max} = \max \left[ \frac{54942.3}{6.11} m_1 \right]$$

S.T.  $m_1 \leq \frac{6.11}{6.11} x_{1 \max}$

Therefore,  $d_{1 \max} = 8992 m_{1 \max} ; m_{1 \max} = 5$

And  $m_{1 \max} \leq x_{1 \max} ; \text{ SO } m_{1 \max} = x_{1 \max} = 5$

Therefore,  $d_{1 \max} = 8992 \times 5 = \underline{44960}$

**At OPN.2**

S.T.  $d_{2 \max} \leq d_{1 \max}$

Or,  $d_{2 \max} \leq 44960$

$$d_{2 \max} = \max \left[ \left( \frac{54942.3}{8.67} \right) \times m_2 \right]$$

$$m_2 \leq \left( \frac{8.67}{8.67} \right) x_{2 \max}$$

Therefore,  $d_{2 \max} = 6337 \times m_{2 \max} ; m_{2 \max} = 5$

S.T.  $m_{2 \max} \leq x_{2 \max} ; \text{ SO } m_{2 \max} = x_{2 \max} = 4$

Therefore,  $d_{2 \max} = 6337 \times 4 = \underline{25348}$

**At OPN.3**

S.T.  $d_{3 \max} \leq d_{2 \max}$

Or,  $d_{3 \max} \leq 25348$

$$d_{3 \max} = \max \left[ \left( \frac{54942.3}{26.44} \right) \times m_3 \right]$$

$$m_3 \leq \left( \frac{26.44}{7.79} \right) x_{3 \max}$$

Therefore,  $d_{3 \max} = 2078 \times m_{3 \max}$

S.T.  $m_3 \leq (3.4)x_3$

$$m_{3 \max} \leq 3x_{3 \max}$$

$$\text{so } m_{3\max} = 6, x_{3\max} = 2$$

Therefore,  $d_{3\max} = 2078 \times 6 = \underline{12468}$

#### At OPN.4

$$\text{S.T. } d_{4\max} \leq d_{3\max}$$

$$d_{4\max} \leq 12468$$

$$d_{4\max} = \max \left[ \left( \frac{54942.3}{28.22} \right) \times m_4 \right]$$

$$m_4 \leq \left( \frac{28.22}{19.30} \right) x_{4\max}$$

Therefore,  $d_{4\max} = 1947 \times m_{4\max}$

S.T.  $m_4 \leq (1.46)x_4$

$$m_{4\max} \leq x_{4\max}$$

$$\text{so } m_{4\max} = x_{4\max} = 6$$

Therefore,  $d_{4\max} = 1947 \times 6 = \underline{11682}$

**Table 5.2 : Summation of  $d_{i\max}$**

$d_1$	44960
$d_2$	25348
$d_3$	12468
$d_4$	11682

$$\text{Final Output} = d_4$$

Therefore, **Final Output = 11682**

#### Revised $m_i, x_i$

Notes that  $m_i$  and  $x_i$  must be integer values, so the term 'round up' is used to make this assumption possible.

$$m_i = \text{round up} \left[ \frac{\text{Final Output} \times (a_i + b_i)}{54942.3} \right]$$

$$x_i = \text{round up} \left[ m_i \times \left( \frac{a_i}{a_i + b_i} \right) \right]$$

e.g.

$$\text{OPN.1 } m_1 = \text{round up} \left[ \frac{11682 \times 6.11}{54942.3} \right]$$

$$m_1 = \text{round up} [1.29] ; \text{ so } m_1 = 2$$

$$x_1 = \text{round up} \left[ 2 \times \left( \frac{6.11}{6.11} \right) \right] ; \text{ so } x_1 = 2$$

$$\text{OPN.2 } m_2 = \text{round up} \left[ \frac{11682 \times 8.67}{54942.3} \right]$$

$$m_2 = \text{round up} [1.84] ; \text{ so } m_2 = 2$$

$$x_2 = \text{round up} \left[ 2 \times \left( \frac{8.67}{8.67} \right) \right] ; \text{ so } x_2 = 2$$

$$\text{OPN.3 } m_3 = \text{round up} \left[ \frac{11682 \times 26.44}{54942.3} \right]$$

$$m_3 = \text{round up} [5.62] ; \text{ so } m_3 = 6$$

$$x_3 = \text{round up} \left[ 6 \times \left( \frac{7.79}{26.44} \right) \right] ; \text{ so } x_3 = 2$$

$$\text{OPN.4 } m_4 = 6, x_4 = 6$$

Then, the results from the assuming data when calculating by hand are as follows:

**Table5.3: Results from calculation by hand (data without space factor)**

operation	$d_i$	$m_i$	$x_i$
1	17984	2	2
2	12674	2	2
3	12468	6	2
4	11682	6	6

## 2. Calculation by using the proposed model

In proposed model, the function 'max' and 'min', except from the objective function, are transferred into equation forms that can be solved by mathematical programming. The results from the assuming data when calculating by using the proposed model and solve by LINDO program are as follows:

Results from calculation by using the proposed model (data without space factor).

```

LAST INTEGER SOLUTION IS THE BEST FOUND
RE-INSTALLING BEST SOLUTION...

OBJECTIVE FUNCTION VALUE

    1)      11682.00

    VARIABLE            VALUE            REDUCED COST
    D4      11682.000000          -1.000000
    D3      12468.000000           0.000000
    D2      12674.000000           0.000000
    D1      17984.000000           0.000000
    M1         2.000000           0.000000
    M2         2.000000           0.000000
    M3         6.000000           0.000000
    M4         6.000000           0.000000
    X1         2.000000           0.000000
    X2         2.000000           0.000000
    X3         2.000000           0.000000
    X4         6.000000           0.000000
  
```

Notes: The program listing for testing the model without space factor is shown in Table A-1 of Appendix A

Comparing these two results, it can be seen that the data from solving the proposed model by program is equal to the data from calculating by hand. Then, the next step is to add the space constraint into the model.

### 5.2.2 Testing with the space factor

The next step is to add the space factor, as it is one constraint of the model to the same assuming data. Then, comparing the results between calculation by hand and calculation by using the proposed model is performed.

- Assume :**
- one operator needs at least 0.5 station to perform work in each operation ( $s_1^o=0.5$ )
  - tooling at operation 1 needs space equal to 1 station ( $s_1^m=1$ )
  - tooling at operation 2 needs space equal to 0.5 station ( $s_2^m=0.5$ )
  - tooling at operation 3 needs space equal to 0.2 station ( $s_3^m = 0.2$ )
  - tooling at operation 4 needs space equal to 0.2 station ( $s_4^m = 1$ )
  - total space factor total space factor must not exceed 10

### 1. Calculation by hand

The concept of the space factor is that the space factor of each operation should be the maximum number between the space factor required by operators and the space factor required by tooling. Or,

Space factor at each operation = max [space factor required by each operator × number of operators, space factor required by each tooling × number of tooling]

**OPN.1** from the previous section  $x_1 = 2$ ,  $m_1 = 2$

$$s_1 = \max [0.5 \times 2, 1 \times 2]$$

Therefore,  $s_1 = 2$

**OPN.2** from the previous section  $x_2 = 2$ ,  $m_2 = 2$

$$s_2 = \max [0.5 \times 2, 0.5 \times 2]$$

Therefore,  $s_2 = 1$

**OPN.3** from the previous section  $x_3 = 2$ ,  $m_3 = 6$

$$s_3 = \max [0.5 \times 2, 0.2 \times 6]$$

Therefore,  $s_3 = 1.2$

**OPN.4** from the previous section  $x_4 = 6$ ,  $m_4 = 6$

$$s_4 = \max [0.5 \times 6, 1 \times 6]$$

Therefore,  $s_4 = 6$

total space factor must not exceed 10

$$s_1 + s_2 + s_3 + s_4 \leq 10$$

However,  $s_1 + s_2 + s_3 + s_4 = 10.2$

So, the easiest way is to reduce each space factor with 1 value (minus 1) and then measure which one has least effect to the output. For example, if we minus the space factor from OPN.1, it means one operator and one tooling will be reduced and the output will be decreased for 8992 items.

The best solution is to reduce one tooling from the operation 4. Then, the results of this solution are as follows:

**Table5.4: Results from calculation by hand (data with space factor)**

Operation	$d_i$	$m_i$	$x_i$	$s_i$
1	17984	2	2	2
2	12674	2	2	1
3	12468	6	2	1.2
4	9735	5	5	5

## 2. Calculation by using the proposed model

The equations from the proposed model are:

$$s_i \geq s_i^0 \times x_i$$



$$s_i \geq s_i^m \times m_i$$

Then, these equations is included into the proposed model and solved by mathematical programming. The results from the assuming data when calculating by using the proposed model and solve by LINDO program are as follows:

Results from calculation by using the proposed model (data with space factor)

LAST INTEGER SOLUTION IS THE BEST FOUND  
RE-INSTALLING BEST SOLUTION...

OBJECTIVE FUNCTION VALUE

1) 9735.000

VARIABLE	VALUE	REDUCED COST
D1	17984.000000	0.000000
D2	12674.000000	0.000000
D3	12468.000000	0.000000
D4	9735.000000	-1.000000
X1	2.000000	0.000000
X2	2.000000	0.000000
X3	2.000000	0.000000
X4	5.000000	0.000000
M1	2.000000	0.000000
M2	2.000000	0.000000
M3	6.000000	0.000000
M4	5.000000	0.000000
S1	2.800000	0.000000
S2	1.000000	0.000000
S3	1.200000	0.000000
S4	5.000000	0.000000

Notes: The program listing for testing the model with space factor is shown in Table A-2 of Appendix A

Comparing these two results, it can be seen that the data from solving the proposed model by program is equal to the data from calculating by hand. Then, it is clear that our proposed model can be used for our intention.

### 5.3 The Application of the Model with Real Data

After testing the proposed model with the assuming data, the same results from two ways of calculation show the applicability of the model that it can be used. Then, the next step is to apply the real data into the proposed model and then compare the results from the proposed model with the results from the existing spreadsheet of the company.

**Table 5.5: Comparisons of the Existing Spreadsheet and Proposed Model**

OPERATION	Existing Spreadsheet			Proposed Model		
	PACK_CAP DGR (d)	@ H/C ( $x_i$ )	@ SPACE ( $s_i$ )	$d_i$	$x_i=m_i$	$s_i$
PRE-TRIM	9937	1	1	9937	1	1
PRE-CLEAN	13209	2	2	9937	2	2
LOAD HEAD	10207	2	2	9937	2	2
GIMBAL BOND	11303	3	3	9937	3	3
FLEX BOND	10447	3	3	9937	3	3
LEAD BOND	10627	3	3	9937	3	3
CAOT LEAD	11168	2	2	9937	2	2
TACK TAIL	10958	2	2	9937	2	2
OVEN			6			6
UNLOAD JIT TOOL	11438	2	2	9937	2	2
LOAD IAT ARM	11168	2	2	9937	2	2
PUSH FLEX & SPOT CLAEN	12008	2	2	9937	2	2
HEAD SET	10958	1	1	9937	1	1
AUTOGRAM	11152	2	3	9937	2	3
SAAM	11468	4	6	9937	4	6
CUT FLEX	13059	1	1	9937	1	1
MRE & REMOVE PRE SHUT	11077	2	3	9937	2	3
FLEX SHUNTING	10349	1	1	9937	1	1
UNLOAD IAT ARM & FOLD FLAPPER	13075	2	2	9937	2	2
Total	9937	37	47	9937	37	47

The data used in this two method is the same. The real data such as the numbers of operator available and tooling available is shown in Table B-1 of Appendix B. Notes that the Oven needed in this assembly line takes place of 6 stations. Thus, the limitation of space factor used in the Proposed Model is 54-6 or 48 stations. The program listing for testing the application of the model is shown in Table B-2 of Appendix B.

From Table 5.5, the data of Proposed Model shows the same results of the numbers of operator and space factor as from the Existing Spreadsheet. However, for the numbers of output at each operation ( $d_i$ ), the results are different. It is because of the first constraint of the Proposed Model that the numbers of output at one operation must relate to the numbers of output at previous operation i.e., the numbers of output at one operation is less than or equal to the numbers of output at previous operation. Thus, Operation 2 cannot produce the output more than the numbers of output at Operation 1 and so on. However, these results indicate that the bottleneck operation is Operation 1.

In Table 5.5,  $d_i$  of Proposed Model show the results of the calculation by LINDO program. If the first operation produces the lowest numbers of output, the results will be shown as in Table 5.5. However, if one want to know the actual capability to produce the output that it can not be the same in each operation as in the Table 5.5, the actual  $d_i$  can be computed from the Equation 4.4 by using the same numbers of operator and tooling.

$$d_i = \left( \frac{T_i}{a_i + b_i} \right) \times \left( \frac{\%Yield \times \%Efficiency}{\%Sampling} \right)_i \times m_i \quad \dots\dots\dots(4.4)$$

This  $d_i$  is denotes as ' $d_i$  Calculate' where the  $d_i$  from LINDO program is denoted as ' $d_i$  LINDO' and both are presented in the Revised Table.

**Revised Table 5.5: Comparisons of the Existing Spreadsheet and Proposed Model**

OPERATION	Existing Spreadsheet			Proposed Model			
	PACK_CAP DGR (d)	@ H/C (x)	@ SPACE (s)	d <sub>i</sub> LINDO	x <sub>i</sub> =m <sub>i</sub>	s <sub>i</sub>	d <sub>i</sub> Calculate
PRE-TRIM	9937	1	1	9937	1	1	9937
PRE-CLEAN	13209	2	2	9937	2	2	13209
LOAD HEAD	10207	2	2	9937	2	2	10207
GIMBAL BOND	11303	3	3	9937	3	3	11303
FLEX BOND	10447	3	3	9937	3	3	10447
LEAD BOND	10627	3	3	9937	3	3	10627
CAOT LEAD	11168	2	2	9937	2	2	11168
TACK TAIL	10958	2	2	9937	2	2	10958
OVEN			6			6	
UNLOAD JIT TOOL	11438	2	2	9937	2	2	11438
LOAD IAT ARM	11168	2	2	9937	2	2	11168
PUSH FLEX & SPOT CLAEN	12008	2	2	9937	2	2	12008
HEAD SET	10958	1	1	9937	1	1	10958
AUTOGRAM	11152	2	3	9937	2	3	11152
SAAM	11468	4	6	9937	4	6	11468
CUT FLEX	13059	1	1	9937	1	1	13059
MRE & REMOVE PRE SHUT	11077	2	3	9937	2	3	11077
FLEX SHUNTING	10349	1	1	9937	1	1	10349
UNLOAD IAT ARM & FOLD FL	13075	2	2	9937	2	2	13075
Total	9937	37	47	9937	37	47	9937

In Revised Table 5.5, the column **d<sub>i</sub> Calculate** is added in the Proposed Model. The objective of revising Table 5.5 is to compare the result of **d<sub>i</sub>** from the LINDO program and **d<sub>i</sub>** from the calculation of Equation 4.4. The results show that the numbers of output when calculating from Equation 4.4 are the same as the results from the Existing Spreadsheet.

In conclusion, by using the Proposed Model and LINDO program, the company will receive the numbers of output (**d<sub>i</sub> LINDO**), the numbers of operator (**x<sub>i</sub>**), the

numbers of tooling ( $m_i$ ) and the space factor ( $s_i$ ) in each operation. Then, if the company want to know the numbers of actual output that can be produced in each operation, the company can compute by using the results of the numbers of operator from the LINDO program and calculate in the Equation 4.4. These numbers are represented in column named ' $d_i$  Calculate'.

In Revised Table 5.5, the results of two methods are the same because of the limited numbers of operator. If the company can allocate more than 37 operators into the line, the results will be different. For instant, if the company removes the constraint that the total numbers of operator in one line are less than 37 operators. The results are as following:



**Table 5.6: Comparisons of the Existing Spreadsheet and Proposed Model  
when remove the constraint of total numbers of operator**

OPERATION	Existing Spreadsheet			Proposed Model			
	PACK_CAP DGR (d <sub>i</sub> )	@ H/C (x <sub>i</sub> )	@ SPACE (s <sub>i</sub> )	d <sub>i</sub> LINDO	x <sub>i</sub> =m <sub>i</sub>	s <sub>i</sub>	d <sub>i</sub> Calculate
PRE-TRIM	9937	1	1	19874	2	2	19874
PRE-CLEAN	13209	2	2	13209	2	2	13209
LOAD HEAD	10207	2	2	13209	3	3	15312
GIMBAL BOND	11303	3	3	11303	3	3	11303
FLEX BOND	10447	3	3	11303	4	4	13928
LEAD BOND	10627	3	3	11303	4	4	14168
CAOT LEAD	11168	2	2	11168	2	2	11168
TACK TAIL	10958	2	2	11152	3	3	16437
OVEN			6			6	
UNLOAD JIT TOOL	11438	2	2	11152	2	2	11438
LOAD IAT ARM	11168	2	2	11152	2	2	11168
PUSH FLEX & SPOT CLAEN	12008	2	2	11152	2	2	12008
HEAD SET	10958	1	1	11152	2	2	21916
AUTOGRAM	11152	2	3	11152	2	3	11152
SAAM	11468	4	6	11152	4	6	11468
CUT FLEX	13059	1	1	11152	1	1	13059
MRE & REMOVE PRE SHUT	11077	2	3	11077	2	3	11077
FLEX SHUNTING	10349	1	1	11077	2	2	20698
UNLOAD IAT ARM & FOLD FL	13075	2	2	11077	2	2	13075
Total	9937	37	47	11077	44	54	11077

The program listing for testing the application of the model when remove the constraint of total numbers of operator is shown in Table B-3 of Appendix B.

From Table 5.6, when the constraint that total numbers of operator are less than 37 is removed, the Existing Spreadsheet is not effected. The results of the Existing Spreadsheet are the same. However, the change is occurred in the calculation from Proposed Model. The new results of Proposed Model show the increasing in the numbers of output, the numbers of operator, the numbers of tooling and space factor. This is

because when removing the constraint of total numbers of operator, the results will increase until they meet another constraint. Table 5.6 shows that if the company can employ more than 37 operators in one line, the suitable solution is to employing 44 operators which can produce 11077 HGA Output per day.

Moreover, in the same manner of Revised Table 5.5, the numbers of output at each operation are shown in two columns: **d<sub>1</sub>LINDO** and **d<sub>1</sub>Calculate** and their meaning are same as presented above.

When looking at the way to achieve this solution, one should found that these two methods based on the different objective. The Proposed Model uses the objective of producing the maximum output with the restriction of operators, tooling and space. Conversely, the Existing Spreadsheet computes the numbers of output in each operation from the demand of HGA per day then, try to use the minimum number of operators to produce to meet this demand rate. From this point of view, it can not conclude that the proposed model is better than the existing spreadsheet because it is based on the different objective.

Even though it can not conclude that which method is better, the proposed model has more ability than the existing one. In the case of cycle time of tooling is more than the cycle time of operator, the proposed model allows the operator to work with more than one tooling as exhibited in the testing model with assuming data, however, the spreadsheet allows one operator to work with one tooling. Moreover, the proposed model has constraint of operator and tooling available for each operation, that the spreadsheet does not have.

For the new method, the objective of the model that we proposed is to maximize the output which can produced under the restriction of resources. The mathematical model can ensure that the solution is closely to the optimal solution. Therefore, this new method is an alternative way for the company to use when the optimal solution is needed.