CHAPTER IV

DATA COLLECTION AND PROCESSING

4.1 Data Collection

The research was taken place in PT. Yoska Prima Inti (YPI). YPI is an automotive component manufacturer and it was established in 1989. YPI is located in Tangerang. The researcher conducted the research about sustainable supplier selection and order allocation. Therefore, the data obtained from the company is the assessment of pairwise comparison for supplier evaluation considering environmental criteria, the data are used to determine the weight of suppliers. The environmental criteria are obtained from literature review and being discussed with the expert. After that, other data are obtained from the company, such as customer's demand, supplier's capacity, purchasing price, and transportation cost to determine the optimum order allocation. Then, incorporating order allocation with risk rating to mitigate the supply risk, by transferring the product from risky supplier to a least risky supplier. The list of risk is obtained from literature review and had been discussed with the expert to select the suitable supply risk, then risk rating is determined by the expert. The expert for this research is only the manager of logistic in PT. Yoska Prima Inti. The detailed data for this research will be shown below.

4.1.1 Supplier Selection

The step of supplier selection is evaluating the supplier with determining the weight of each supplier and the method is using AHP. The aspect of environmental criteria is considered in this research. The environmental criteria are obtained from literature review and had been discussed with the expert. To do the supplier evaluation accurately, it is necessary to calculate criteria weights to know the rank of alternatives. Therefore, the result is the weight of criteria and the rank of each supplier.

A. Environmental Criteria

The first step is identifying the environmental criteria. The environmental criteria are obtained from literature review and discussion with the expert. The criteria of environmental is adopted from Song et al. (2017)[1]. The list of environmental criteria is shown in Table 4.1 shown below.

Table 4.1 Environmental criteria

Criteria	Reference
EMS (Environmental Management System)	1
Eco-design	1
3R (Reduce, Reuse, Recycle)	1

B. Hierarchy of Supplier Selection

Figure 4.1 shows the hierarchy of supplier selection of PT. Yoska Prima Inti. The hierarchy consists of level 0, which is the goal. Then, level 1, which shows the criteria of 3 environmental criteria according to environmental aspect mentioned earlier. Then, hierarchy of level 2 shows the alternatives of supplier, which will be evaluated for supplier selection.

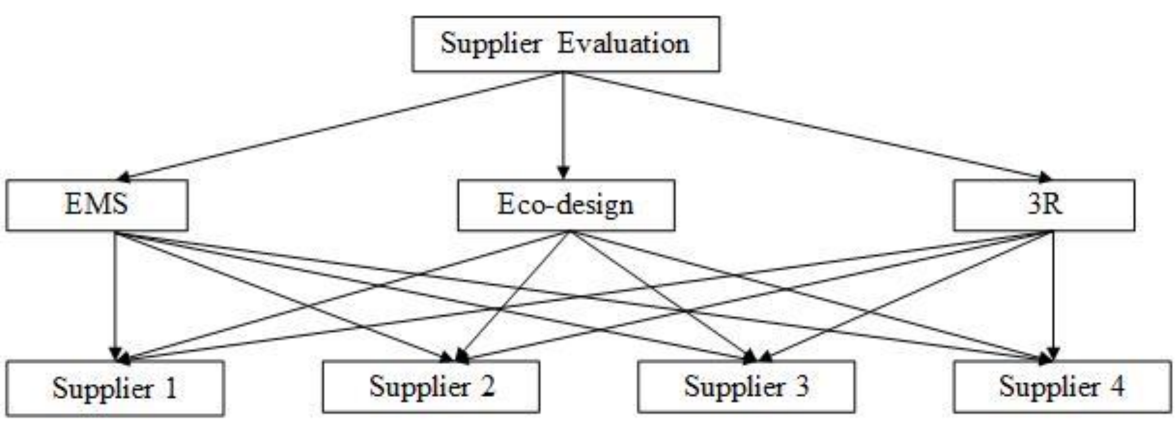


Figure 4.1 The hierarchy

C. Weight of Criteria Determination

To determine the pairwise comparison, comparisons were made between each pair of criteria and alternative. Data for determining the weight of criteria for supplier evaluation are obtained from questionnaire which filled by the expert. The comparison of importance of the criteria will be written in a matrix of pairwise comparison as follows. Table 4.2 shows the pairwise comparison matrices between criteria, followed by the pairwise comparison matrices between alternatives. Table 4.3 shows the pairwise comparison matrices criteria of EMS (environmental management system), Table 4.4 shows the pairwise comparison matrices criteria of eco-design, while Table 4.5 shows the pairwise comparison matrices criteria of 3R (reduce, reuse, and recycle).

Table 4.2 Pairwise comparison matrices between criteria

Criteria	EMS	Eco-design	3R
EMS	1	0.5	0.250
Eco-design	2	1	0.333
3R	4	3	1

Table 4.3 Pairwise comparison matrices criteria of EMS

EMS	S1	S2	S3	S4
S1	1	0.50	0.333	0.250
S2	2	1	0.50	0.333
S3	3	2	1	0.333
S4	4	3	3	1

Table 4.4 Pairwise comparison matrices criteria of Eco-design

Eco-design	S1	S2	S3	S4
S1	1	0.250	0.50	0.33
S2	4	1	1	0.50
S3	2	1	1	0.50
S4	3	2	2	1

Table 4.5 Pairwise comparison matrices criteria of 3R

3R	S1	S2	S3	S4
S1	1	0.33	0.50	0.25
S2	3	1	0.50	0.50
S3	2	2	1	0.33
S4	4	2	3	1

4.1.2 Supply chain network

There are 4 suppliers, which supply plate material to PT. Yoska Prima Inti. The supply network of inbound logistic is shown in Figure 4.2. Every supplier is located in different city. The list of 4 suppliers with its location is presented in Table 4.6. There are 5 types of plate materials which differ from thickness, length, and width. The list of plate materials is shown in Table 4.7.

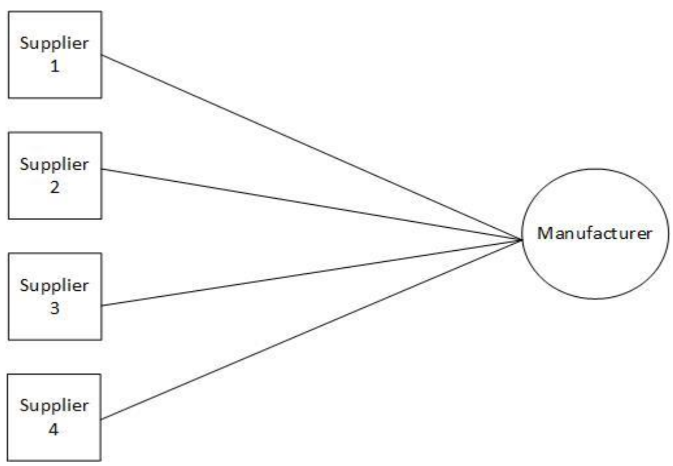


Figure 4.2 Supply chain network

Table 4.6 List of supplier

No.	Suppliers	Location
S1	PT. Mera Puti Steel	Tangerang
S2	PT. Indometal Mitrabuana	Cikarang
S3	PT. Sumber Logam Aneka Baja	Jakarta
S4	PT. Posco IJPC	Karawang

Table 4.7 List of plate materials

No.	Products	Code
A1	2.3 X 1219 X 2438	SPHC – PO
A2	2.6 X 1219 X 2438	SPHC - PO
A3	2.0 X 1219 X 2438	SPHC - PO
A4	1.2 X 1219 X 2438	SPCC
A5	1.4 X 1219 X 2438	SPCC

4.1.3 Demand

The demand is from customer for 5 different plate materials from May – July in 2018. PT. Yoska always does the forecast for every 3 months. The demand of PT. Yoska Prima Inti of each product is shown in table 4.8.

Table 4.8 Demand

Products	Months		
	May	June	July
A1	450	450	450
A2	1150	1150	1150
A3	250	250	250
A4	3250	3250	3250
A5	2300	2300	2300

4.1.4 Capacity of Suppliers

The capacity from each suppliers for each material is different, and it is shown in table 4.9.

Table 4.9 Capacity of suppliers

Products	S1	S2	S3	S4
A1	150	150	100	150
A2	450	350	300	400
A3	100	100	100	100
A4	1050	1000	1000	1000
A5	1000	600	600	600

4.1.5 Unit Purchasing Price

The unit purchasing price from each supplier for every plate materials is shown in Table 4.10 below.

Table 4.10 Unit purchasing price

Products	S1	S2	S3	S4
A1	12,500	12,400	12,600	12,475
A2	12,500	12,400	12,600	12,475
A3	12,500	12,400	12,600	12,475
A4	12,000	12,100	12,200	12,050
A5	12,000	12,100	12,200	12,050

4.1.6 Transportation Cost

Transportation cost from each supplier is presented in Table 4.11 below.

Table 4.11 Transportation cost

Suppliers	Cost
1	1,152,000.00
2	3,744,000.00
3	1,632,000.00
4	4,500,000.00

4.1.7 The Proposed Model

The function of proposed model is to support in obtaining the optimal order allocation regarding each supplier. The proposed model of multi-objective function was developed to deal with a sustainable supplier selection problem with multiple products and multiple sourcing decisions. The list of decision variables, notation, and parameter for the model are provided as follows.

Decision variable

Q_{si} : Quantity of product s^{th} allocated from supplier i^{th} to manufacturer

Y_i : 1 if an order allocated from supplier i^{th},

0 otherwise

Notation

s : Product indices (s=1,2,..,5)

i : Supplier indices (i=1,2,..,4)

Parameter

V_{si} : Capacity of i^{th} supplier for s^{th} product

D_s : Demand of product s^{th}

P_{si} : Purchasing price per unit of product s^{th} delivered by supplier i^{th}

TC_i : Transportation cost of supplier i^{th} per delivery

W_i : Weight of supplier i^{th}

Objective functions and constraints of the proposed model are presented as follows:

a. Minimizing total purchasing cost (Z1)

The objective is determining the order allocation based on total purchasing cost, which consist of purchasing price and transportation cost.

$$Min\ Z1 = \sum_{s=1}^{5}\sum_{i=1}^{4} Q_{si}*P_{si} + \sum_{i=1}^{4} TC_i*Y_i \quad (4.1)$$

b. Maximizing supplier evaluation (Z2)

This objective function is determining the order allocation based on supplier evaluation with considering weight of supplier.

$$Max\ Z2 = \sum_{s=1}^{5}\sum_{i=1}^{4} Q_{si}*W_i \quad (4.2)$$

Constraint

a. Capacity constraint

The capacity constraint means that the quantity allocated for each product from each supplier should be less than or equal to supplier's capacity.

$$\sum_{s=1}^{5}\sum_{i=1}^{4} Q_{si} \leq V_{si} \quad (4.3)$$

b. Demand Constraint

The demand constraint requires that all of the demand from customers for each product from each supplier. The quantity allocated should be more than or equal to demand.

$$\sum_{s=1}^{5} \sum_{i=1}^{4} Q_{si} \geq D_s \qquad (4.4)$$

c. Non-negative constraint

$$Q_{si} \geq 0 \qquad (4.5)$$

1.1.8 Weighted-sum method

The objective function of Z3 is defined to be minimized. w_1 and w_2 are the weights of objective functions. a is defined as the index of the objectives. This method is formulated as follows. Since a maximizing objective can be converted to a minimizing objective by multiplying it by -1 (i.e. maximize $f_i(x)$ = minimize $-f_i(x)$).

$$Min\ Z3 = w_1 z_1 - w_2 z_2 \qquad (4.6)$$

Subject to:

$$\sum_a w_a = 1 \qquad (4.7)$$

$$w_a \geq 0 \qquad (4.8)$$

Equations (4.3)-(4.5)

4.2 Data Processing

4.2.1 Weight of Criteria Calculation

Calculate the weight of criteria of level 1, which are EMS (environmental management system), eco-design, and 3R (reduce, reuse, and recycle). Below are the steps of determining weight of criteria and weight of alternative calculation.

Step 1: Add all the value of b_{ij} from each column of matrices pairwise comparison to normalize the matrix, which shows in Table 4.12.

Table 4.12 Total pairwise comparison matrices between criteria

Criteria	EMS	Eco-design	3R
EMS	1	0.5	0.250
Eco-design	2	1	0.333
3R	4	3	1
Total	7	4.5	1.6

Step 2: Dividing b_{ij} with the total value of the column which resulted in normalized matrices of criteria which shows in Table 4.13.

Table 4.13 Normalized matrices between criteria

Criteria	EMS	Eco-design	3R
EMS	0.143	0.111	0.158
Eco-design	0.286	0.222	0.211
3R	0.571	0.667	0.632

Step 3: Sum up the lines to obtain the relative priority of the criteria or the eigen value. Table 4.14 shows the calculation of weight or local priority of criteria.

Table 4.14 Calculation of local priority of criteria.

Criteria	EMS	Eco-design	3R	Eigen value
EMS	0.143	0.111	0.158	0.137
Eco-design	0.286	0.222	0.211	0.239
3R	0.571	0.667	0.632	0.623

The result of calculation of the eigen value of each line is the local priority of calculation.

- Local priority of criteria of EMS = 0.137 (13.7%)
- Local priority of criteria of eco-design = 0.239 (23.9%)
- Local priority of criteria of 3R = 0.623 (62.3%)

4.2.2 Weight of Alternatives Calculation

Calculate the weight of alternatives of level 2 which consist of supplier 1, supplier 2, supplier 3, and supplier 4. Calculate the rest of normalized matrices between alternatives. The normalized matrices of alternatives are shown in Table 4.15, 4.16, 4.17, which the normalized matrices between alternative of environmental management system, eco-design, and 3R respectively.

Table 4.15 Normalized matrices between criteria of EMS

EMS	S1	S2	S3	S4
S1	0.10	0.077	0.069	0.130
S2	0.20	0.154	0.103	0.174
S3	0.30	0.308	0.207	0.174
S4	0.40	0.462	0.621	0.522

Table 4.16 Normalized matrices between criteria of Eco-design

EMS	S1	S2	S3	S4
S1	0.10	0.059	0.111	0.143
S2	0.40	0.235	0.222	0.214
S3	0.20	0.235	0.222	0.214
S4	0.30	0.471	0.444	0.429

Table 4.17 Normalized matrices between criteria of 3R

EMS	S1	S2	S3	S4
S1	0.10	0.062	0.10	0.120
S2	0.30	0.188	0.10	0.240
S3	0.20	0.375	0.20	0.160
S4	0.40	0.375	0.60	0.480

From the calculation above, researcher obtain the result of the weight of alternatives. The eigen value for every criteria with alternatives are presented in Table 4.18, 4.19, 4.20 which shows the priority weight of each alternative.

Table 4.18 Eigen value of criteria EMS

Alternatives	Eigen Value
S1	0.094
S2	0.158
S3	0.247
S4	0.501

Table 4.19 Eigen value of criteria Eco-design

Alternatives	Eigen Value
S1	0.103
S2	0.268
S3	0.218
S4	0.411

Table 4.20 Eigen value of criteria 3R

Alternatives	Eigen Value
S1	0.096
S2	0.207
S3	0.234
S4	0.464

4.2.3 Global Priority

Global priority is used to determine the rank of each element. Final weights of criteria are generated by considering the degree of importance between criteria and degree of dependencies with other criteria. Final weight of criteria was obtained by multiplying weight of criteria with matrix of weight of alternatives. The result of global priority is shown in Table 4.21. The calculation of global priority is as follows:

Global priority of criteria of EMS of supplier 1 is 0.137 x 0.094 = 0.013 (1.3%)

Table 4.21 Result of global priority calculation of criteria

Goal	Criteria	Weight	Alternatives	Alt. Weight Evaluation
Supplier Performance Evaluation	Environmental management system	0.137	S1	0.013
			S2	0.022
			S3	0.034
			S4	0.069
	Eco-design	0.239	S1	0.025
			S2	0.064
			S3	0.052
			S4	0.098
	3R	0.623	S1	0.060
			S2	0.129
			S3	0.146
			S4	0.289

After the global priority obtained, the weight of each alternative is calculated with sum all weight of global priority of each supplier and the ranks of each supplier are obtained. The weight supplier evaluation and rank for suppliers are presented below. Table 4.22 shows the overall weight alternatives.

Table 4.22 Overall weight alternative

Alternatives	Eigen Value	Rank
S1	0.097	4
S2	0.215	3
S3	0.232	2
S4	0.456	1

Table 4.22 above shows that the first supplier priority is supplier 4 with the weight of 0.456 for supplying the material based on supplier evaluation. The second priority is supplier

3 with the weight of 0.232. The third priority is supplier 2 with the weight of 0.215, while the fourth priority is supplier 1 with the weight of 0.097.

4.2.4 Consistency Ratio

After the weight of each criteria and alternative are obtained, consistency ratio is calculated to know whether the data obtained is consistent or not. The parameter of consistency ratio should be less than 0.1. If consistency ratio is more than 0.1, then the data from pairwise comparison matrices should be redefined.

Calculations of consistency ratio following the steps as follows:

a. Multiplying the matrices with the weight.
b. Summing up the results of multiplications per row.
c. The sum of each row divided by the weight and the results are summed.
d. Results are divided by the number of elements, so scalar x will be obtained.
e. Consistency Index (*CI*) = (*x* -*n*) / (*n*-*1*)
f. Consistency Ratio = *CI* / *RI*, where *RI* (random index) is the random consistency index. If the consistency ratio ≤ 0.1, hence the results of the calculation of the data can be justified. List of RI can be seen in Table 4.23.

Table 4.23 Random Index

n	1	2	3	4	5	6	7	8	9	10	11
RI	0.0	0.0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

The result of consistency test is following the calculation mentioned above. Table 4.24 shows the result of consistency ratio.

Table 4.24 Result for consistency ratio

Pairwise comparison	*CR*	Consistent/Inconsistent
Between criteria	0.015	Consistent
Criteria of EMS	0.032	Consistent
Criteria of eco-design	0.036	Consistent
Criteria of 3R	0.065	Consistent

Table 4.24 above shows the consistency ratio, it is indicated that the data of calculating the weight of criteria are consistent. After obtaining the weight of supplier, then calculate the order allocation based on the supplier evaluation and minimizing total purchasing cost and maximizing the supplier evaluation.

4.2.5 Multi Objective Linear Programming

The model of order allocation is according to Equation 4.1 , which consist of objective function and constraint. The following multi objective linear programming model is formulated. Lingo 17.0 software is used to do the calculation.

a. Objective function

The model of Z1 is the objective function of order allocation to find the minimum total cost which consists of total purchasing price and total transportation cost, the model is shown in Equation 4.1 below. The model shown below is only for one month since the demand for each item for 3 months is the same.

$$\begin{aligned} Min\ Z_1 = {} & 12{,}500*Q_{11} + 12{,}400*Q_{12} + 12{,}600*Q_{13} + 12{,}475*Q_{14} + 12{,}500*Q_{21} + \\ & 12{,}400*Q_{22} + 12{,}600*Q_{23} + 12{,}475*Q_{24} + 12{,}500*Q_{31} + 12{,}400*Q_{32} + \\ & 12{,}600*Q_{33} + 12{,}475*Q_{34} + 12{,}000*Q_{41} + 12{,}100*Q_{42} + 12{,}200*Q_{43} + \\ & 12{,}050*Q_{44} + 12{,}000*Q_{51} + 12{,}100*Q_{52} + 12{,}200*Q_{53} + 12{,}050*Q_{54} + \\ & \textstyle\sum_{S=1}^{5}(1{,}152{,}000*Y_{s1} + 3{,}744{,}000*Y_{s2} + 1{,}632{,}000*Y_{s3} + 4{,}500{,}000*Y_{s4}) \quad (4.9) \end{aligned}$$

The objective function of Z2 is to maximize the supplier evaluation which the weight has determined earlier to find the order allocation. The model is shown in Equation 4.2. Model shown below is the calculation of the weight of supplier and the quantity supplied by each supplier

$$\begin{aligned} Max\ Z_2 = {} & 0.097*Q_{11} + 0.215*Q_{12} + 0.232*Q_{13} + 0.456*Q_{14} + 0.097*Q_{21} + 0.215*Q_{22} + \\ & 0.232*Q_{23} + 0.456*Q_{24} + 0.097*Q_{31} + 0.215*Q_{32} + 0.232*Q_{33} + 0.456*Q_{34} + \end{aligned}$$

$$0.097*Q_{41} + 0.215*Q_{42} + 0.232*Q_{43} + 0.456*Q_{44} + 0.097*Q_{51} + 0.215*Q_{52} + 0.232*Q_{53} + 0.456*Q_{54} \quad (4.10)$$

The objective function of Z3 is the combination of Z1 and Z2 into single objective. Since considering using weighted-sum method and also the Lingo Software can't process with multiple objective function. The weight of objective function is determined by the expert for the importance of each objective. In this case the weight of Z1 is 0.8, while the weight of Z2 is 0.2. Therefore, the objective function is formulated as follows.

$$\begin{aligned} Min\ Z_3 = {} & 0.8*(12{,}500*Q_{11} + 12{,}400*Q_{12} + 12{,}600*Q_{13} + 12{,}475*Q_{14} + 12{,}500*Q_{21} + \\ & 12{,}400*Q_{22} + 12{,}600*Q_{23} + 12{,}475*Q_{24} + 12{,}500*Q_{31} + 12{,}400*Q_{32} + \\ & 12{,}600*Q_{33} + 12{,}475*Q_{34} + 12{,}000*Q_{41} + 12{,}100*Q_{42} + 12{,}200*Q_{43} + \\ & 12{,}050*Q_{44} + 12{,}000*Q_{51} + 12{,}100*Q_{52} + 12{,}200*Q_{53} + 12{,}050*Q_{54} + \\ & \textstyle\sum_{S=1}^{5}(1{,}152{,}000*Y_{s1} + 3{,}744{,}000*Y_{s2} + 1{,}632{,}000*Y_{s3} + 4{,}500{,}000*Y_{s4})) - 0.2* \\ & (0.097*Q_{11} + 0.215*Q_{12} + 0.232*Q_{13} + 0.456*Q_{14} + 0.097*Q_{21} + 0.215*Q_{22} + \\ & 0.232*Q_{23} + 0.456*Q_{24} + 0.097*Q_{31} + 0.215*Q_{32} + 0.232*Q_{33} + 0.456*Q_{34} + \\ & 0.097*Q_{41} + 0.215*Q_{42} + 0.232*Q_{43} + 0.456*Q_{44} + 0.097*Q_{51} + 0.215*Q_{52} + \\ & 0.232*Q_{53} + 0.456*Q_{54}) \end{aligned} \quad (4.11)$$

b. Constraint

The model has the constraint in determining the order allocation. The constraints as follows:

1. Capacity constraint

   The capacity of each supplier to manufacturer for each product is different. The capacity of s^{th} product from i^{th} supplier is shown in Equation 4.4, 4.5, 4.6, 4.7, 4.8 for 1st supplier. The capacity of 2nd supplier is shown in Equation 4.9, 4.10, 4.11, 4.12, 4.13. The capacity of 3rd supplier is shown in Equation 4.14, 4.15, 4.16, 4.17, 4.18 The capacity of 4th supplier is shown in Equation 4.19, 4.20, 4.21, 4.22, 4.23.

   $$Q_{11} \leq 150 \quad (4.4)$$

$$Q_{21} \leq 450 \quad (4.5)$$

$$Q_{31} \leq 100 \quad (4.6)$$

$$Q_{41} \leq 1050 \quad (4.7)$$

$$Q_{51} \leq 1000 \quad (4.8)$$

$$Q_{12} \leq 150 \quad (4.9)$$

$$Q_{22} \leq 350 \quad (4.10)$$

$$Q_{32} \leq 100 \quad (4.11)$$

$$Q_{42} \leq 1000 \quad (4.12)$$

$$Q_{52} \leq 600 \quad (4.13)$$

$$Q_{13} \leq 100 \quad (4.14)$$

$$Q_{23} \leq 300 \quad (4.15)$$

$$Q_{33} \leq 100 \quad (4.16)$$

$$Q_{43} \leq 1000 \quad (4.17)$$

$$Q_{53} \leq 600 \quad (4.18)$$

$$Q_{14} \leq 150 \quad (4.19)$$

$$Q_{24} \leq 400 \quad (4.20)$$

$$Q_{34} \leq 100 \quad (4.21)$$

$$Q_{44} \leq 1000 \quad (4.22)$$

$$Q_{54} \leq 600 \quad (4.23)$$

2. Demand constraint

PT. Yoska has the same demand for 3 months. The demand for products A1, A2, A3, A4, A5 are shown in Equation 4.24, 4.25, 4.26, 4.27, 4.28 respectively.

$$Q_{11} + Q_{12} + Q_{13} + Q_{14} \geq 450 \quad (4.24)$$

$$Q_{21} + Q_{22} + Q_{23} + Q_{24} \geq 1150 \quad (4.25)$$

$$Q_{31} + Q_{32} + Q_{33} + Q_{34} \geq 250 \quad (4.26)$$

$$Q_{41} + Q_{42} + Q_{43} + Q_{44} \geq 3250 \quad (4.27)$$

$$Q_{51} + Q_{52} + Q_{53} + Q_{54} \geq 2300 \quad (4.28)$$

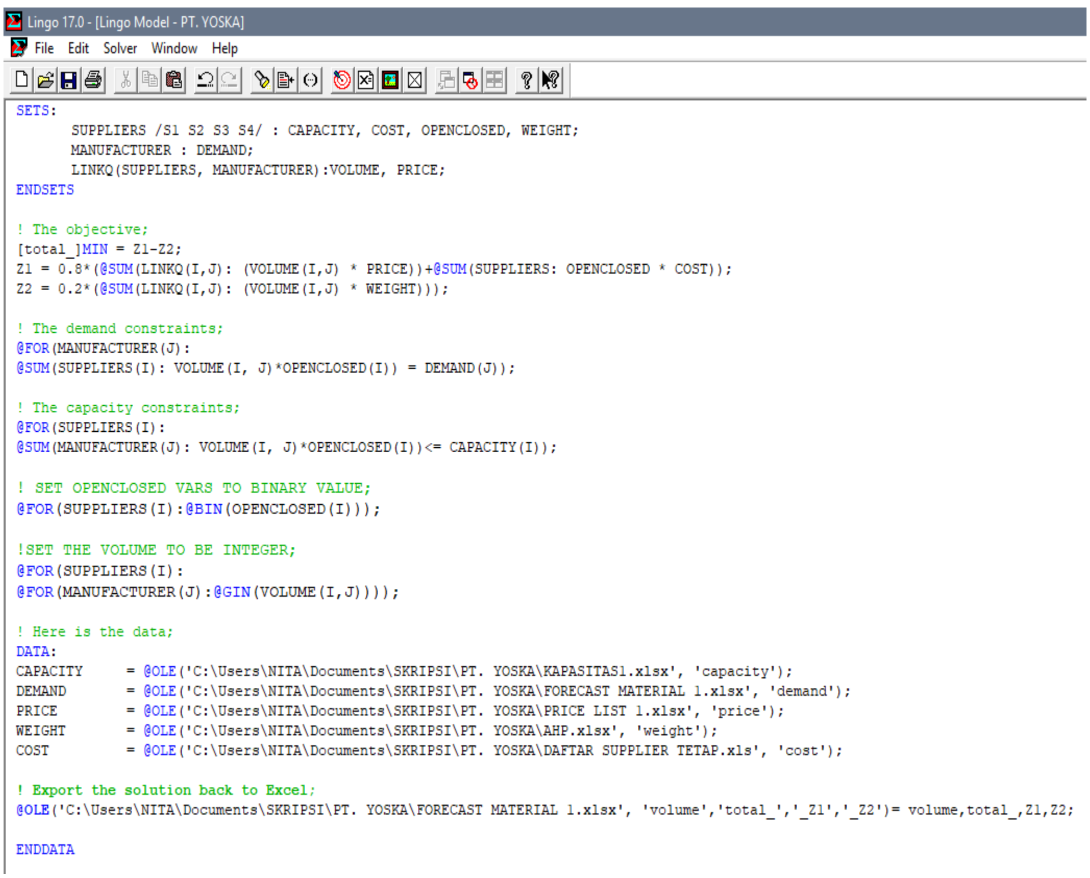
3. Non negative constraint

   This non negative constraint is to ensure that quantity of s^{th} product supplied by i^{th} supplier is non-negative value. Equation 4.29 shows the non-negative constraint.

   $$Q_{si} \leq 0 \quad (4.29)$$

4.2.6 Lingo Model for Multi Objective Linear Programming

The calculation is done with mathematical model of Multi Objective Linear Programming (MOLP). Lingo 17.0 software is used to determine the optimal solution of decision variable. The mathematical model is shown in Figure 4.3.



Lingo 17.0 - [Lingo Model - PT. YOSKA]
File Edit Solver Window Help

```
SETS:
      SUPPLIERS /S1 S2 S3 S4/ : CAPACITY, COST, OPENCLOSED, WEIGHT;
      MANUFACTURER : DEMAND;
      LINKQ(SUPPLIERS, MANUFACTURER):VOLUME, PRICE;
ENDSETS

! The objective;
[total_]MIN = Z1-Z2;
Z1 = 0.8*(@SUM(LINKQ(I,J): (VOLUME(I,J) * PRICE))+@SUM(SUPPLIERS: OPENCLOSED * COST));
Z2 = 0.2*(@SUM(LINKQ(I,J): (VOLUME(I,J) * WEIGHT)));

! The demand constraints;
@FOR(MANUFACTURER(J):
@SUM(SUPPLIERS(I): VOLUME(I, J)*OPENCLOSED(I)) = DEMAND(J));

! The capacity constraints;
@FOR(SUPPLIERS(I):
@SUM(MANUFACTURER(J): VOLUME(I, J)*OPENCLOSED(I))<= CAPACITY(I));

! SET OPENCLOSED VARS TO BINARY VALUE;
@FOR(SUPPLIERS(I):@BIN(OPENCLOSED(I)));

!SET THE VOLUME TO BE INTEGER;
@FOR(SUPPLIERS(I):
@FOR(MANUFACTURER(J):@GIN(VOLUME(I,J))));

! Here is the data;
DATA:
CAPACITY     = @OLE('C:\Users\NITA\Documents\SKRIPSI\PT. YOSKA\KAPASITAS1.xlsx', 'capacity');
DEMAND       = @OLE('C:\Users\NITA\Documents\SKRIPSI\PT. YOSKA\FORECAST MATERIAL 1.xlsx', 'demand');
PRICE        = @OLE('C:\Users\NITA\Documents\SKRIPSI\PT. YOSKA\PRICE LIST 1.xlsx', 'price');
WEIGHT       = @OLE('C:\Users\NITA\Documents\SKRIPSI\PT. YOSKA\AHP.xlsx', 'weight');
COST         = @OLE('C:\Users\NITA\Documents\SKRIPSI\PT. YOSKA\DAFTAR SUPPLIER TETAP.xls', 'cost');

! Export the solution back to Excel;
@OLE('C:\Users\NITA\Documents\SKRIPSI\PT. YOSKA\FORECAST MATERIAL 1.xlsx', 'volume','total_','_Z1','_Z2')= volume,total_,Z1,Z2;

ENDDATA
```

Figure 4.3 Lingo model

The steps in completion of mathematical model into Lingo 17.0 software are as follows:

1. Defining the sets

   Each set involved in the mathematical model is defined by set name. After that, define the member of the set and the attribute of each set.

```
SETS:
SUPPLIERS /S1 S2 S3 S4/ : CAPACITY, COST, OPENCLOSED, WEIGHT;
MANUFACTURER : DEMAND;
LINKQ(SUPPLIERS, MANUFACTURER): VOLUME, PRICE;
ENDSETS
```

2. Making a matrix data for input and output on Excel

   Data is imported from Excel and the result is being exported back to Excel with making a matrix table, for example is table for volume which defined by the set of LINKQ(SUPPLIERS, MANUFACTURER) with matrix data shown in Table 4.25.

Table 4.25 Matrix data

Product	Supplier			
	1	2	3	4
A1				
A2				
A3		Q_{32}		
A4				
A5				

3. Defining range in Excel software

   Define the range for the spreadsheet in Excel is to identify which certain data is being imported or exported.

4. Importing data from Excel

   Importing the data from spreadsheet is using @OLE function, for example to input the data for price:

   PRICE = @OLE('C:\Users\NITA\Documents\SKRIPSI\PT. YOSKA\PRICE LIST 1.xlsx', 'price');

5. Exporting data from Excel

   Exporting the data from Excel which exports solutions back out to spreadsheets using @OLE, for example export the solution of Q_{ij} back to spreadsheet:

   @OLE('C:\Users\NITA\Documents\SKRIPSI\company profile\PT. YOSKA\FORECAST MATERIAL 1.xlsx', ‘volume’,’total_’,’Z1’,’Z2’) = volume,total_,Z1,Z2;

6. Defining the mathematical model of multi objective function

   $Min\ Z_1 = \sum_{s=1}^{5}\sum_{i=1}^{4} Q_{si}*P_{si} + \sum_{i=1}^{4} TC_i*Y_i$

   $Max\ Z_2 = \sum_{s=1}^{5}\sum_{i=1}^{4} Q_{si}*W_{si}$

   The mathematical model for Lingo.

```
[total_]MIN = Z1-Z2;
Z1 = 0.8*(@SUM(LINKQ(I,J): (VOLUME(I,J) * PRICE))+  @SUM(SUPPLIERS:
OPENCLOSED * COST));
Z2 = 0.2*(@SUM(LINKQ(I,J): (VOLUME(I,J) * WEIGHT)));
```

7. Define the constraints

a. Capacity (V_{si})

   $\sum_{s=1}^{5}\sum_{i=1}^{4} Q_{si} \geq V_{si}$

   The capacity of each supplier for every type product is different. Therefore, the quantity to be allocated can't be more than capacity and the mathematical model in Lingo is written as:

```
@FOR(SUPPLIERS(I): @SUM(MANUFACTURER(J):
VOLUME(I,J)*OPENCLOSED(I))<= CAPACITY(I));
```

b. Demand (D_s)

   $\sum_{s=1}^{5}\sum_{i=1}^{4} Q_{si} \geq D_s$

   The demand from manufacturer for every type of product is different. Therefore, the quantity to be allocated can't be less than demand and the mathematical model in Lingo is written as:

```
@FOR(MANUFACTURER(J): @SUM(SUPPLIERS(I):
VOLUME(I,J)*OPENCLOSED(I)) = DEMAND(J));
```

c. Openclosed value

   Y_i : 1 if an order allocated from supplier *i*,

   0 otherwise

   Openclosed value is a binary value which is 0 and 1. If 1, it means that the transportation is applied to the total purchasing cost, while 0 is not. The model in Lingo is written as follows:

@FOR(SUPPLIERS(I): @BIN(OPENCLOSED(I)));

d. Integer value

The quantity that supplied by supplier to manufacturer should be integer. Therefore the model in Lingo is written as follows:

@FOR(SUPPLIERS(I): @FOR (MANUFACTURER (J) :
@GIN(OPENCLOSED(I)));

Result of the optimal solution or the initial order allocation quantity is presented in Table 4.26. The total purchasing cost is Rp 324,684,600 and details of cost and initial order allocation per month are shown in Table 4.26 below. After initial order allocation is determined, then risk analysis will be applied to the calculation to obtain revised order allocation corresponding to risk ratings.

Table 4.26 Optimal solution of order allocation quantity

Weight (w_1, w_2)	Product	Month	Supplier				Objective Function	
			1	2	3	4	Z1	Z2
(0.8, 0.2)	A1	May	150	150	0	150	12,001,800	8.750396
		June	150	150	0	150	12,001,800	8.750396
		July	150	150	0	150	12,001,800	8.750396
	A2	May	450	0	300	400	17,343,200	22.36212
		June	450	0	300	400	17,343,200	22.36212
		July	450	0	300	400	17,343,200	22.36212
	A3	May	100	100	50	0	7,718,400	4.861331
		June	100	100	50	0	7,718,400	4.861331
		July	100	100	50	0	7,718,400	4.861331
	A4	May	1,050	1,000	200	1,000	40,174,400	63.19731
		June	1,050	1,000	200	1,000	40,174,400	63.19731
		July	1,050	1,000	200	1,000	40,174,400	63.19731
	A5	May	1,000	600	100	600	30,990,400	44.72425
		June	1,000	600	100	600	30,990,400	44.72425
		July	1,000	600	100	600	30,990,400	44.72425

4.2.7 Risk Management

The risk management is applied to the calculation of determining the revised order allocation based on risk rating, in order to mitigate the supply risk. The risk management consists of risk identification, risk measurement, risk evaluation, and risk mitigation. The risk mitigation is the result of revised order allocation plan.

A. Risk Identification

The first step is to identify the risk that might occur in suppliers. The risk is obtained from literature review and discussion with the expert to identify the suitable risk events for the risk of suppliers. The risk events are adopted from Kırılmaz & Erol (2017)[1] and Zsidisin (2003)[2]. The list of risk is presented in Table 4.27 below.

Table 4.27 The list of risk

Risk	Reference
Delivery failures	1
Quality problems	1
Price/cost increases	1
Inability to meet customer requirements	2
Discontinuity of supply	2
Bankruptcy of supplier	1
Supplier capacity	1
Machine breakdowns	1
Malfunction of IT system	1
Accident risk	1
Extreme weather condition	1

Delivery failures are related to late deliveries and lost & damaged packages. The manufacturer should have the reliable supplier to avoid this risk, so that manufacturer could provide goods to customer right in time without any disruption.

Quality problems are related to quality failures such as shipment of parts that do not meet with the certain specification of a product. Manufacturer needs to aware of selecting the reliable suppliers.

Price/cost increases are the high risk that is not easily to avoid, which the cost is likely to arise due to factors of inflation and exchange risk which related to foreign exchange rates. This type of risk happens a lot because the unstable condition of economic in Indonesia.

Inability to meet customer requirement relates to the capability of supplier to meet the requirement from manufacturer for product requirements. It also refers to product liability and integrity where the part must meet requirements.

Discontinuity of supply is an essential input of products or processes that is discontinued by the supplier. Manufacturer needs to aware this risk in order to always be able to fulfil customer demand.

Bankruptcy of supplier is related to the disruption from supplier in supplying the product. The manufacturer, especially the logistic manager should devise the strategy to collect information on their supplier's financial risk in order to avoid sudden large scale disruption.

Supplier capacity is related capability of supplier in meeting the customer demand, The uncertainty demand has the impact of the flow of supply, which supplier sometimes does not able to fulfill the demand from customers. The manufacturer has to find the reliable supplier in order to always have suppliers that have the ability to always fulfill the demand.

Machine breakdowns are related to disruption of supply when supplier cannot meet customer demand because of disruption in production process. Manufacturer needs to always consider the possible risk that might happen in the near time and in the future.

Malfunction of IT system is related to the flow process of production. IT system helps the system integrated to run the process efficiently. The malfunction of IT system could lead to disruption in supplying the product.

Accident risk is related to risk that happen during the working hours. There is always possibility of the accident occurs. In order to avoid the disruption in supply chain, manufacturer has to select the reliable supplier.

Extreme weather condition is related to uncertainty in climate change. Sometimes the unpredictable of natural disaster has the impact of discontinuity of supply chain. This type of risk has the lowest scale of probability, but it has the highest impact.

B. Risk Measurement

The second step is to do risk measurement. In order to determine the level of risk or risk rating, the measurement is considering 2 perspective of impact or consequences and likelihood or probability. The impact is the consequences if the risk is occurred and the likelihood is the probability of risk that likely to occur or the occurrence frequency of a risk event. The impact and likelihood scale is obtained by literature and had been discussed with the expert. Table 4.28 shows the impact index, while Table 4.29 shows the likelihood index.

Table 4.28 Impact index

Risk Impact	Impact index	Definition
Catastrophic	5	Discontinue the production for 1 week or more
Major	4	Discontinue of production for 2-3 days
Moderate	3	Slows down of production for 3-5 days

Risk Impact	Impact index	Definition
Minor	2	Decrease in customer service level
Insignificant	1	Unaffected customer service level

Table 4.29 Likelihood index

Risk likelihood	Likelihood index	Definition
Almost certain	5	1-2 times a month
Likely	4	1-2 times in 6 months
Moderate	3	Once a year
Unlikely	2	Once every 2 years
Rare	1	1-2 times every 2 years or more

After determining the scale of impact and likelihood, the next step is to assess every supplier according to impact and likelihood index. The assessment is determined by interviewing the expert. Table 4.30 shows the assessment of impact. The assessment of impact is applied to every supplier, which the impact is directly affect the manufacturer not the supplier.

Table 4.30 The assessment of impact

Risk	Impact
Delivery failures	2
Quality problems	3
Price/cost increases	1
Inability to meet quantity demand	3
Discontinuity of supply	4
Bankruptcy of supplier	3
Supplier capacity	3
Machine breakdownss	3
Malfunction of IT system	1
Accident risk	1
Extreme weather condition	1

The assessment of likelihood is to measure on how often the risk might occur. The likelihood assessment of supplier 1, supplier 2, supplier 3, and supplier 4 are shown in Table 4.31, 4.32, 4.33, and 4.34 respectively.

Table 4.31 The assessment of likelihood of supplier 1

Risk	Likelihood
Delivery failures	2
Quality problems	3
Price/cost increases	3
Inability to meet quantity demand	1
Discontinuity of supply	1
Bankruptcy of supplier	1
Supplier capacity	2
Machine breakdowns	3
Malfunction of IT system	2
Accident risk	1
Extreme weather condition	1

Table 4.32 The assessment of likelihood of supplier 2

Risk	Likelihood
Delivery failures	1
Quality problems	2
Price/cost increases	3
Inability to meet quantity demand	1
Discontinuity of supply	1
Bankruptcy of supplier	1
Supplier capacity	2
Machine breakdowns	1
Malfunction of IT system	1
Accident risk	1
Extreme weather condition	1

Table 4.33 The assessment of likelihood of supplier 3

Risk	Likelihood
Delivery failures	1
Quality problems	3
Price/cost increases	3
Inability to meet quantity demand	1
Discontinuity of supply	1
Bankruptcy of supplier	1
Supplier capacity	2
Machine breakdowns	2
Malfunction of IT system	2
Accident risk	1
Extreme weather condition	1

Table 4.34 The assessment of likelihood of supplier 4

Risk	Likelihood
Delivery failures	2
Quality problems	3
Price/cost increases	3
Inability to meet quantity demand	1
Discontinuity of supply	1
Bankruptcy of supplier	1
Supplier capacity	2
Machine breakdowns	3
Malfunction of IT system	2
Accident risk	1
Extreme weather condition	1

After risk measurement are done, then calculate the risk rating, the impact is multiplied by the likelihood. Result of risk rating is shown in Table 4.35 below. In table 4.35, there are total risk ratings for each supplier. From the result, it can be obtained which supplier has the highest risk and lowest risk.

Table 4.35 Risk rating of each supplier

Risk	Risk Rating			
	Supplier 1	Supplier 2	Supplier 3	Supplier 4
Delivery failures	4	2	2	2
Quality problems	9	6	9	3
Price/cost increases	3	3	3	2
Inability to meet quantity demand	3	3	3	3
Discontinuity of supply	4	4	4	4
Bankruptcy of supplier	3	3	3	3
Supplier capacity	6	6	6	6
Machine breakdowns	9	3	6	3
Malfunction of IT system	2	1	2	1
Accident risk	1	1	1	1
Extreme weather condition	1	1	1	1
Total risk rating	45	33	40	29

C. Risk Evaluation

To evaluate risk, it can be done by considering the consequence and probability of each risk. The risk evaluation categories is obtained from literature review and brainstorming with the expert. The risk index between 2 of 15 is identified as lower bound and upper bound respectively of acceptable risk. A supplier with high level of risk should be eliminated because it is intolerable and unreasonable to mitigate with such high level of risk. Risk criteria determined by the manufacturer that risk index between 6 and 12 are undesirable and needs mitigation immediately.

D. Risk Mitigation

The next step, the risks should be mitigated by reallocated the order quantity or shifting the order from risky supplier to the less risky or reliable supplier. After the total risk rating is obtained, to normalize the value of risk rating, the least risky supplier is set to zero and this supplier is subtracted from the other supplier. Table 4.36 shows the normalized value of risk rating.

Table 4.36 Normalized value of risk of risk rating

Supplier	Total risk rating	Subtraction risk rating	Normalized value
1	45	16	0.516
2	33	4	0.129
3	40	11	0.355
4	29	0	0
	Total	31	1

These normalized values represent the risk status of suppliers, so the normalized value can be used to find quantity transferred as a percentage of the initial procurement quantity. The result of reallocation order quantity shows in Table 4.37 below. This model will be used as a parameter for determining the revised order allocation.

Table 4.37 Result of reallocation order quantity

Product	Supplier	Initial order allocation	Normalized risk values	Quantity transferred	Remaining quantity in supplier	Remaining capacity of supplier
A1	1	150	0.516	77	73	0
	2	150	0.129	19	131	0
	3	0	0.355	0	0	100
	4	150	0	0	150	0
A2	1	450	0.516	232	218	0
	2	0	0.129	0	0	350
	3	300	0.355	106	194	0
	4	400	0	0	400	0
A3	1	100	0.516	52	48	0
	2	100	0.129	13	87	0
	3	50	0.355	18	32	50
	4	0	0	0	0	100
A4	1	1050	0.516	542	508	0
	2	1000	0.129	129	871	0
	3	200	0.355	71	129	800
	4	1000	0	0	1000	0
A5	1	1000	0.516	516	484	0
	2	600	0.129	77	523	0
	3	100	0.355	35	65	500
	4	600	0	0	600	0

Another parameter used for the calculation of revised order allocation is shown in Table 4.38, which is the difference between normalized risk values. This value will be used to determine the order allocation for each product corresponding to risk rating of each supplier.

Table 4.38 Difference between normalized risk values

R_{ij}	N_{ij}
R_{12}	0.387
R_{13}	0.161
R_{14}	0.516
R_{24}	0.129
R_{32}	0.226
R_{34}	0.355

After determining the parameters, those values will be used to determine the order allocation of product transfer from risky supplier to less risky supplier. The order allocation of every product is calculated with considering the constraint of each product. The objective function is to maximize the product transfer from risky supplier to less risky supplier. The value of objective function doesn't represent any quantity, but the maximization satisfies the condition of transferring product from risky supplier to a less risky supplier. The model is solved with Lingo 17.0 software. The model is shown in Equation 4.30 below. This objective function can be applied for determining order allocation for every product.

There are 5 products that are going to be calculated. The calculation of revised order allocation for every product and from each supplier is presented as follows:

1. **Product A1**

a. Objective function

$$Max: 0.387*X_{12} + 0.161*X_{13} + 0.516*X_{14} + 0.129*X_{24} + 0.226*X_{32} + 0.355*X_{34} \quad (4.30)$$

b. Constraints

Equation 4.31, 4.32, 4.33 are the capacity constraint, while Equation 4.34, 4.35, 4.36 are the constraint for product transfer, and Equation 4.37 is the non-negative constraint.

X_{13} - X_{32}- X_{34}≤100 (4.31)

$X_{12} + X_{32} - X_{24} \leq 0$ (4.32)

$X_{14} + X_{34} + X_{24} \leq 0$ (4.33)

$X_{14} + X_{12} + X_{13} \leq 77$ (4.34)

$X_{24} \leq 19$ (4.35)

$X_{34} \leq 0$ (4.36)

$X_{ij} \geq 0$ (4.37)

The optimal solution of product A1 is shown in Table 4.39. In the table 4.39 below is mentioned quantity that should be transfer from risky supplier to a less risky supplier.

Table 4.39 Optimal solution A1

R_{ij}	N_{ij}
R_{12}	0
R_{13}	77
R_{14}	0
R_{24}	0
R_{32}	0
R_{34}	0

In Table 4.39 above, it shows that the product transferred from supplier 1 to supplier 3 is 77 items. In table 4.40 also shows the difference between initial and revised quantity corresponding to the risk rating. The revised order allocation of supplier 3 is obtained product transferred from supplier 1, which is 77 items, and the revised order allocation of supplier 1 is obtained from quantity remaining in supplier and the other are obtained from the initial order allocation since there is no product transfer from these suppliers.

Table 4.40 Initial and revised order quantity A1

Suppliers	Initial order allocation	Risk rating	Revised order allocation
1	150	45	73
2	150	33	150
3	0	40	77
4	150	29	150
Total	450		450

2. Product A2

a. Objective function

Max: $0.387*X_{12} + 0.161*X_{13} + 0.516*X_{14} + 0.129*X_{24} + 0.226*X_{32} + 0.355*X_{34}$ (4.38)

b. Constraints

Equation 4.39, 4.40, and 4.41 are the capacity constraint, while Equation 4.42 and 4.43 are the constraint for product transfer, and Equation 4.44 is the non-negative constraint.

$$X_{12}+ X_{32}- X_{24} \leq 350 \quad (4.39)$$

$$X_{13}- X_{32} - X_{34} \leq 0 \quad (4.40)$$

$$X_{14}+ X_{34}+ X_{24} \leq 0 \quad (4.41)$$

$$X_{14}+ X_{13}+ X_{12} \leq 232 \quad (4.42)$$

$$X_{32}+ X_{34} \leq 106 \quad (4.43)$$

$$X_{ij} \geq 0 \quad (4.44)$$

The optimal solution of product A2 is shown in Table 4.41. In the table 4.41 below is mentioned quantity that should be transfer from risky supplier to a less risky supplier.

Table 4.41 Optimal solution A2

R_{ij}	N_{ij}
R_{12}	232
R_{13}	0
R_{14}	0
R_{24}	0
R_{32}	106
R_{34}	0

In Table 4.41 above, it shows that the product transferred from supplier 1 to supplier 2 is 232 items, and from supplier 3 to supplier 2 is 106 items. In table 4.42 also shows the difference between initial and revised quantity corresponding to the risk rating. The revised order allocation of supplier 2 is obtained from product transferred from supplier 1 and supplier 3, which resulted in 338 items, and the revised order allocation of supplier 1 and supplier 3 are obtained from remaining quantity in the supplier and another order allocation is from initial order allocation since there is no product transfer from this supplier.

Table 4.42 Initial and revised order quantity *A2*

Suppliers	Initial order allocation	Risk profile	Revised order allocation
1	450	45	218
2	0	33	338
3	300	40	194
4	400	29	400
Total	1150		1150

3. **Product A3**

a. Objective function

Max: $0.387*X_{12} + 0.161*X_{13} + 0.516*X_{14} + 0.129*X_{24} + 0.226*X_{32} + 0.355*X_{34}$ (4.45)

b. Constraints

Equation 4.46, 4.47, and 4.48 are the capacity constraint, while Equation 4.49. 4.50, and 4.51 are the constraint for product transfer, and Equation 4.52 is the non-negative constraint.

$X_{13} - X_{32} - X_{34} \leq 50$ (4.46)

$X_{14} + X_{34} + X_{24} \leq 100$ (4.47)

$X_{12} + X_{32} - X_{24} \leq 0$ (4.48)

$X_{13} + X_{12} + X_{14} \leq 52$ (4.49)

$X_{24} \leq 13$ (4.50)

$X_{34} + X_{32} \leq 18$ (4.51)

$X_{ij} \geq 0$ (4.52)

The optimal solution of product *A3* is shown in Table 4.43. In the table 4.43 below is mentioned quantity that should be transfer from risky supplier to a less risky supplier.

Table 4.43 Optimal solution A3

R_{ij}	N_{ij}
R_{12}	0
R_{13}	0
R_{14}	52
R_{24}	13
R_{32}	5
R_{34}	13

In Table 4.43 above, it shows that the product transferred from supplier 1 to supplier 4 is 52 items, from supplier 2 to supplier 4 is 13 items, from supplier 3 to supplier 2 is 5 items, from supplier 3 to supplier 4 is 13 items. In table 4.44 also shows the difference between initial and revised quantity corresponding to the risk rating. The revised order allocation of supplier 4 is obtained from product transferred from supplier 1, supplier 2, and supplier 3, which resulted in 83 items, supplier 3 will supply 37 items because there is still 5 items left, which cannot be transfer to supplier 2, and the other revised order allocation of other supplier are obtained from remaining quantity in the supplier.

Table 4.44 Initial and revised order quantity A3

Suppliers	Initial order allocation	Risk profile	Revised order allocation
1	100	45	48
2	100	33	87
3	50	40	37
4	0	29	83
Total	250		250

4. Product A4

a. Objective function

$$Max: 0.387*X_{12} + 0.161*X_{13} + 0.516*X_{14} + 0.129*X_{24} + 0.226*X_{32} + 0.355*X_{34} \quad (4.53)$$

b. Constraints

Equation 4.54, 4.55, and 4.56 are the capacity constraint, while Equation 4.57 and 4.58 are the constraint for product transfer, and Equation 4.59 is the non-negative constraint.

$$X_{13} - X_{32} - X_{34} \leq 800 \quad (4.54)$$

$$X_{12} + X_{32} - X_{24} \leq 0 \quad (4.55)$$

$X_{14} + X_{34} + X_{24} \leq 0$ (4.56)

$X_{14} + X_{13} + X_{12} \leq 542$ (4.57)

$X_{24} \leq 129$ (4.58)

$X_{32} + X_{34} \leq 71$ (4.59)

$X_{ij} \geq 0$ (4.60)

The optimal solution of product A4 is shown in Table 4.45. In the table 4.45 below is mentioned quantity that should be transfer from risky supplier to a less risky supplier.

Table 4.45 Optimal solution A4

R_{ij}	N_{ij}
R_{12}	0
R_{13}	542
R_{14}	0
R_{24}	0
R_{32}	0
R_{34}	0

In Table 4.45 above, it shows that the product transferred from supplier 1 to supplier 3 is 542 items. Table 4.46 also shows the difference between initial and revised quantity corresponding to the risk rating. The revised order allocation of supplier 3 is obtained from product transferred from supplier 1 and the initial order allocation, which resulted in 742 items, the revised order allocation of supplier 1 is only 508 left, and the other are obtained from initial order allocation.

Table 4.46 Initial and revised order quantity A4

Suppliers	Initial order allocation	Risk profile	Revised order allocation
1	1050	45	508
2	1000	33	1000
3	200	40	742
4	1000	29	1000
Total	3250		3250

5. Product *A5*

a. Objective function

Max: $0.387*X_{12} + 0.161*X_{13} + 0.516*X_{14} + 0.129*X_{24} + 0.226*X_{32} + 0.355*X_{34}$ (4.61)

b. Constraints

Equation 4.62, 4.63, and 4.64 are the capacity constraint, while Equation 4.65, 6.66, and 6.67 are the constraint for product transfer, and Equation 4.68 is the non-negative constraint.

$$X_{13} – X_{32} – X_{34} \leq 500 \quad (4.62)$$

$$X_{12} + X_{32} – X_{24} \leq 0 \quad (4.63)$$

$$X_{14} + X_{34} + X_{24} \leq 0 \quad (4.64)$$

$$X_{14} + X_{12} + X_{13} \leq 516 \quad (4.65)$$

$$X_{24} \leq 77 \quad (4.66)$$

$$X_{34} + X_{32} \leq 35 \quad (4.67)$$

$$X_{ij} \geq 0 \quad (4.68)$$

The optimal solution of product A5 is shown in Table 4.47 with total solver iterations of 4 iterations. In the table 4.47 below, it is mentioned quantity that should be transferred from risky supplier to a less risky supplier.

Table 4.47 Optimal solution A5

R_{ij}	N_{ij}
R_{12}	0
R_{13}	500
R_{14}	0
R_{24}	0
R_{32}	0
R_{34}	0

In Table 4.47 above, it shows that the product transferred from supplier 1 to supplier 3 is 500 items. In table 4.48 also shows the difference between initial and revised quantity corresponding to the risk rating. The revised order allocation of supplier 3 is obtained from product transferred from supplier 1, which resulted in 600 items, revised order from supplier 1 is only 500 left, and the other revised order allocation of other supplier are obtained from initial order allocation.

Table 4.48 Initial and revised order quantity A5

Suppliers	Initial order allocation	Risk profile	Revised order allocation
1	1000	45	500
2	600	33	600
3	100	40	600
4	600	29	600
Total	2300		2300