# **Introduction**

A large car manufacturer operates multiple assembly facilities to assemble trucks. There are 4 (01 – 04) assembly lines that can manufacture trucks within a single large manufacturing location.

The car manufacturer gets their auto parts from a supplier. The supplier has a fleet of 3 different trucks types which they used to transport the auto parts to each of the four assembly lines. The parts can be loaded into a 5 Tonne (5T), 8 Tonne (8T) and 10 Tonne (10T) truck type based on the volume of the truck.

Each truck has a different rental cost and once a truck is used, regardless of the number of orders on the truck, the cost of the truck is expensed. The cost of the truck would include driver hourly rate and fuel surcharge by distance per delivery trip. The distance and time matrix between the supplier and the plant will be provided.

The supplier is looking at optimising the use of their fleet of trucks to meet the contracted demand of the car manufacturer to each assembly line. In addition, the supplier’s customer has a commitment to ensure CO2 is minimised because of the environmental policy of the customer.

Hence the objectives are to minimise the cost of the truck and trip assignments as well as to minimise the CO2 emission.

# **Problem Statement of Multiple Objective Optimisation Model**

## **Problem Definition**

To determine the most optimal assignment of trucks for a supplier to deliver a set of orders to each assembly line, ensuring that transportation cost is minimised and carbon dioxide emissions is minimised, the following assumptions hold for the proposed model in this project.

Because carbon dioxide emissions is critical to

1. The model assumes that the shipping cost on a given route is directly proportional to the volume of units shipped on that route and the truck type
2. The shipper has a fleet of trucks of 3 different types (5T, 8T and 10T trucks) and all trucks are available for deliveries at any time
3. The shipper’s fleet consists of a fixed number of 5T, 8T and 10T trucks
4. Cost of rental of trucks differ by truck type
5. Fleet size is fixed for each type of truck
6. The carbon dioxide cost on a given route is directly proportional to the distance travelled, the truck type and the number of trips
7. Carbon dioxide emissions ratio is fixed as per country

The **Table 1** below shows the necessary parameters and decisions variables.

**Table 1: Necessary notations and decision variables**

|  |  |
| --- | --- |
| **Set of Indices** | |
|  | set of truck types ( = 1, 2, …I) where I = 3 |
|  | set of assembly line ( = 1, 2, …J) where J = 4 |
| **Parameters** | |
|  | cost of trucking the parts by supplier 1 using truck type to assembly line |
|  | distance from supplier 1 to assembly line j |
|  | rental rate per distance for truck |
|  | fuel surcharge per distance for truck |
|  | capacity of truck type |
|  | volume of parts required assembly line |
|  | Fleet size of truck type |
|  | carbon dioxide emission expressed as a cost of using 1 unit of truck type to assembly line |
|  | Adjusted emission factor assuming speed of travel is 70kmh |
| **Decision Variables** | |
|  | no. of trucks of type to use for delivery of volume to assembly line j |
|  | no. of trips for truck size of truck type to assembly line j |

The **Table 2** below shows the tableau for the transportation cost model for each truck type to assembly line j.

**Table 2: Tableau to model the transportation cost**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Trucking Cost** | **To** | | | | |
| **Truck Type** | Assembly Line 1 | Assembly Line 2 | Assembly Line 3 | Assembly Line 4 | Total Supply (cbm) |
| 5T ( |  | .. | .. | .. | (256 cbm) |
| 8T ( | .. | .. | .. | .. | (450 cbm) |
| 10T ( | .. | .. | .. | .. | (636 cbm) |
| Total Demand (cbm) rounded up | 303 cbm | 880 cbm | 679 cbm | 380 cbm | Supply = 2242 cbm  Demand = 2242 |

The **Table 3** shows the tableau for the carbon dioxide emission model for each truck type to assembly line j.

**Table 3: Tableau to model the carbon dioxide emission**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Trucking Cost** | **To** | | | | |
| **Truck Type** | Assembly Line 1 | Assembly Line 2 | Assembly Line 3 | Assembly Line 4 | Total Supply (cbm) |
| 5T ( |  | .. | .. | .. | (256 cbm) |
| 8T ( | .. | .. | .. | .. | (450 cbm) |
| 10T ( | .. | .. | .. | .. | (636 cbm) |
| Total Demand (cbm) rounded up | 303 cbm | 880 cbm | 679 cbm | 380 cbm | Supply = 2242 cbm  Demand = 2242 |

## **Problem Formulation**

The first objective function of the proposed model given in Eq. (1) minimised the transportation cost of the total orders to each of the assembly lines. The objective function proposed model also minimises carbon dioxide (CO2) emissions. The second objective function is given in Eq. (2).

**Objective:**

Eq. (1) Min (z) =

where = 3 and = 4

=

Cost of delivering the good using truck type to assembly line is dependent on the distance travelled to assembly line based on the rate per distance for the truck and the fuel surcharge per distance to assembly line .

Eq. (2) Min (z) =

where = 3 and = 4

=

Carbon cost of delivering the good using truck type to assembly line is dependent on the distance travelled to assembly line and the carbon emission rate per KM

**Subject to**

Eq. (3)

Eq. (4)

Eq. (5)

Eq. (6)

Eq. (7)

Eq. (8)

Eq. (9)

Eq. (10)

Eq. (11)

Eq. (12)

Eq. (13)

Eq. (14)

Eq. (15)

Eq. (16)

Eq. (17)

Eq. (18)

Let the above constraints be denoted by ***S***, and vector ***a*** = (

Constraints (3) to (6) determines the maximum supply using each truck types. Eq. (7) ensures that the maximum number of trucks used for each type must be within the fleet x trip size. Eq (8) to (11) determines the maximum demand for each assembly line. Finally, Eq (12) to (18) ensures the non-negativity of variables.

# Implementation and Computation Results

Weighted Goal Programming (WGP) method can be used to solve the multiple objective decision making problem in this project where can be positive and negative deviations corresponding to the goal of the objective function.

**Objective:**

Eq. (19) Min (z) =

**Subject to**

for all *i*.

where and are over and under achievements of the *ith* goal, respectively.

**We first solved for objective 1** - the minimised transportation cost model and the decision variable values are as shown below.

|  |  |  |  |
| --- | --- | --- | --- |
| **Scenario** | **Objective 1 (Min. Transportation Cost)** | | |
|  |  | Value |
| Baseline | 5T : 2; 1; 0; 1  8T : 4; 0; 1; 2  10T : 1; 5; 3; 1 | 5T : 1; 1; 0; 1  8T : 1; 0; 1; 2  10T : 3; 1; 2; 1 | 1874 |

The solution to minimise the transportation cost in transporting the auto-parts is to plan the schedule for the truck fleets as follows:

Assembly line 1:

2 X 5 Ton trucks (Single trip);4 X 8Ton trucks (Single trip) and 1 X 10 Ton trucks (Three trips)

Assembly line 2:

1 X 5Ton trucks (Single trip) and 5 X 10 Ton trucks (Single trip)

Assembly line 3:

1 X 8 Ton trucks (Single trip) and 3 X 10Ton trucks (Two trips)

Assembly line 4:

1 X 5 Ton trucks (Single trip); 2 X 8 Ton trucks (Two trips) and 1 X 10 Ton trucks (Single trip)

The resulted schedule will achieve a minimum transportation cost (objective 1 value) of $1,874 and a derived carbon dioxide emission cost (objective 2 value) of $602.97.

**Next we solved for objective 2** as follows:

|  |  |  |  |
| --- | --- | --- | --- |
| **Scenario** | **Objective 2 (Min. CO2 emission cost)** | | |
|  |  | Value |
| Baseline | 5T : 0; 1; 0; 5  8T : 8; 0; 0; 0  10T : 1; 0; 1; 2 | 5T : 0; 11; 0; 1  8T : 1; 0; 0; 0  10T : 1; 0; 7; 1 | 651.5745 |

The solution to minimise carbon dioxide emission cost to transport the auto-parts is to plan the schedule for the truck fleets as follows:

Assembly line 1:

8 Ton trucks (Single trip) and 1 X 10 Ton trucks (Single trip)

Assembly line 2:

1 X 5 Ton trucks (Eleven trips)

Assembly line 3:

1 X 10Ton trucks (Seven trips)

Assembly line 4:

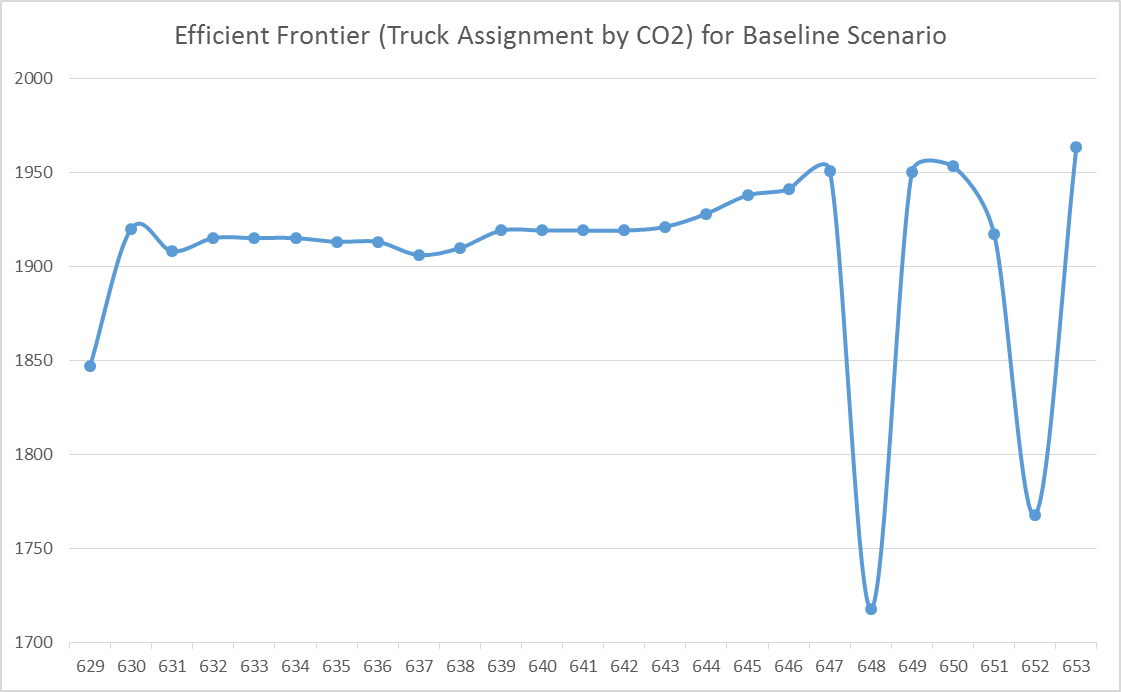
5 X 5 Ton trucks (Single trip) and 2 X 10 Ton trucks (Single trip)

The resulted schedule will achieve a minimum carbon dioxide emission cost (objective 2 value) of $651.58 and a derived transportation cost (objective 1 value) of $2,166.

To have a sense of the potential set of efficient solutions, the efficient frontier was plot in the objective space as shown in Chart 1 below. For the CO2 emission cost between 602.97 and 651.58, the outputs for CO2 emission and truck assignment (transportation cost) are obtained and plotted. More details can be found in the excel file under Annex.

The unusual shape of the frontier curve might be explained by the quadratic objective functions as well as the CO2 emission function. As observation from the chart, the transportation cost are relatively insensitive over the CO2 values over a certain value range suggesting that there are transportation cost are more sensitive to other drivers and unless there is a high penalty cost involved for the ensuring that CO2 emission level is maintained at certain standard, company is likely to place greater emphasis in minimising transportation cost and side-lined the CO2 emission if there is a need to compromise one of the objective.

**Chart 1: Efficient Frontier in Transport Cost and CO2 Emission Objective Space**



**An alternative approach is to determine a compromise solution using the Pre-emptive (Lexicographic) Optimisation method assuming that transportation cost is more important compared with carbon dioxide emission cost.**

We solve for,

Min (z)=

Subject to

= 1,874

|  |  |  |  |
| --- | --- | --- | --- |
| **Scenario** | **Objective 2 (Min. CO2 Emission Cost)** | | |
|  |  | Value |
| Baseline | 5T : 0; 0; 7; 4  8T : 3; 1; 2; 1  10T :5; 4; 3; 1 | 5T : 1; 1; 1; 1  8T : 1; 3; 0; 1  10T : 1; 1; 1; 2 | 662.71 |

The solution obtained is 662.71 carbon dioxide emission cost, 1,874 transportation cost.

**Hence the final compromised solution is to plan the schedule for the truck fleets as follows:**

Assembly line 1:

3 x 8 Ton trucks (Single trip) and 5 x 10 Ton trucks (Single trip)

Assembly line 2:

1 x 8 Ton truck (Three trips) and 4 x10 Ton trucks (Single trip)

Assembly line 3:

7 x 5 Ton trucks (Single trip) and 3x 10Ton trucks (Single trip)

Assembly line 4:

4x 5 Ton trucks (Single trip), 1 x 8 Ton truck (Single trip) and 1 x 10 Ton trucks (Two trips)

**Preemptive Goal Programming method can also be considered in solving the problem when the optimal solution is not feasible and the supplier can accept a compromise solution as long as his goals are met.**

1. Assuming that the environment policy required that the supplier maintained below a certain level of carbon dioxide emission level. And to achieve the standards, the supplier has a goal of not more than 700 in CO2 emission cost; and
2. It also has a goal to keep the transportation cost to be below or not exceeding 2200.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Scenario** | **Goal Program** | | | |
|  |  | Objective 1 Value | Objective 2 Value |
| Baseline | 5T : 14; 0; 0; 0  8T : 0; 1; 0; 1  10T : 0; 1; 2; 1 | 5T : 1; 1; 1; 1  8T : 4; 7; 1; 1  10T : 4; 0; 4; 4 | 2157 | 676.13 |

The solution obtained is 676.13 carbon dioxide emission cost and 2,157 transportation cost while meeting the two goals.

**Hence, the final compromised solution is to plan the schedule for the truck fleets as follows:**

Assembly line 1:

14 x 5 Ton trucks (Single trip)

Assembly line 2:

1 x 8 Ton truck (Seven trips)

Assembly line 3:

2 x 10 Ton trucks (Four trips)

Assembly line 4:

1 x 8 Ton trucks (Single trip) and 1 x 10 Ton trucks (Four trips)

# **Sensitivity Analysis**

The optimisation model is also tested on various scenarios settings to observe using insights for decision making.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Scenario** | | **Demand (j)** | | **Truck Rental rate (i)** | | **Fuel Surcharge** | | **Volume of each truck – cbm (i)** | | **Fleet Size (i)** | | **CO2 adjusted emission factor** | | | **Objective 1**  **Value** | | **Objective 2**  **Value** | |
| Baseline | | 8119.31 (j=1)  5796.17 (j=2)  8530.65 (j=3)  5191.73 (j=4) | | $4.50 (i=1)  $5.00 (i=2)  $5.50 (i=3) | | 2.6% | | 32 (i=1)  46 (i=2)  58 (i=3) | | 18 (i=1)  9 (i=2)  15 (i=3) | | 0.003568708 | | | 1874 | | 651.5745 | |
| Truck Rental Change | | 8119.31 (j=1)  5796.17 (j=2)  8530.65 (j=3)  5191.73 (j=4) | | $3.50 (i=1)  $5.00 (i=2)  $6.00 (i=3) | | 2.6% | | 32 (i=1)  46 (i=2)  58 (i=3) | | 18 (i=1)  9 (i=2)  15 (i=3) | | 0.003568708 | | | 1945 | | 651.5745 | |
| Fuel Surcharge Rate Change | | 8119.31 (j=1)  5796.17 (j=2)  8530.65 (j=3)  5191.73 (j=4) | | $4.50 (i=1)  $5.00 (i=2)  $5.50 (i=3) | | 1.6% (i=1)  2.8% (i=2)  3.2% (i=3) | | 32 (i=1)  46 (i=2)  58 (i=3) | | 18 (i=1)  9 (i=2)  15 (i=3) | | 0.003568708 | | | 1924 | | 651.5745 | |
| Fleet Size Change | | 8119.31 (j=1)  5796.17 (j=2)  8530.65 (j=3)  5191.73 (j=4) | | $4.50 (i=1)  $5.00 (i=2)  $5.50 (i=3) | | 2.6% | | 32 (i=1)  46 (i=2)  58 (i=3) | | 10 (i=1)  15 (i=2)  20 (i=3) | | 0.003568708 | | | 1850 | | 635.0877 | |
| Volume Change | | 8119.31 (j=1)  5796.17 (j=2)  8530.65 (j=3)  5191.73 (j=4) | | $4.50 (i=1)  $5.00 (i=2)  $5.50 (i=3) | | 2.6% | | 35 (i=1)  45 (i=2)  55 (i=3) | | 18 (i=1)  9 (i=2)  15 (i=3) | | 0.003568708 | | | 1689 | | 659.1404 | |
| Demand Change | | 9119.31 (j=1)  7796.18 (j=2)  2530.66 (j=3)  2191.73 (j=4) | | $4.50 (i=1)  $5.00 (i=2)  $5.50 (i=3) | | 2.6% | | 32 (i=1)  46 (i=2)  58 (i=3) | | 18 (i=1)  9 (i=2)  15 (i=3) | | 0.003568708 | | | 1306 | | 498.8340 | |
| CO2 Adjusted Emission Factor | | 8119.31 (j=1)  5796.17 (j=2)  8530.65 (j=3)  5191.73 (j=4) | | $4.50 (i=1)  $5.00 (i=2)  $5.50 (i=3) | | 2.6% | | 32 (i=1)  46 (i=2)  58 (i=3) | | 18 (i=1)  9 (i=2)  15 (i=3) | | 0.003568708 (i=1)  0.008568708 (i=2)  0.013568708 (i=3) | | | 1874 | | 1424.979 | |
| **Scenario** | | **Objective 1** | | | | | | **Objective 2** | | | | | **Goal Program** | | | | | |
|  | |  | | Value | |  | |  | | Value |  | |  | | Value | |
| Baseline | | 5T : 2; 1; 0; 1  8T : 4; 0; 1; 2  10T : 1; 5; 3; 1 | | 5T : 1; 1; 0; 1  8T : 1; 0; 1; 2  10T : 3; 1; 2; 1 | | 1874 | | 5T : 0; 1; 0; 5  8T: 8; 0; 0; 0  10T : 1; 0; 1; 2 | | 5T : 0; 11; 0; 1  8T : 1; 0; 0; 0  10T : 1; 0; 7; 1 | | 651.5745 | 5T : 6; 0; 0; 1  8T: 1; 0; 1; 2  10T : 4; 3; 1; 1 | | 5T : 1; 2; 1; 1  8T : 5; 2; 1; 1  10T : 0; 2; 6; 3 | | 0 | |
| Truck Rental Change | | 5T : 1; 0; 0; 0  8T : 0; 7; 1; 0  10T : 4; 0; 6; 1 | | 5T : 6; 0; 0; 0  8T : 0; 1; 1; 0  10T : 1; 0; 1; 5 | | 1945 | | 5T : 0; 1; 0; 5  8T : 1; 0; 0; 0  10T : 1; 0; 7; 2 | | 5T : 0; 11; 0; 1  8T : 8; 0; 0; 0  10T : 1; 0; 1; 1 | | 651.5745 | 5T : 1; 1; 0; 0  8T: 0; 3; 1; 0  10T : 7; 0; 3; 1 | | 5T : 1; 6; 0; 0  8T : 0; 1; 5; 0  10T : 1; 0; 1; 5 | | 0.16 | |
| Fuel Surcharge Rate Change | | 5T : 1; 1; 2; 5  8T : 4; 0; 2; 0  10T : 3; 1; 4; 1 | | 5T : 2; 1; 1; 1  8T : 1; 0; 1; 0  10T : 1; 5; 1; 2 | | 1924 | | 5T : 0; 11; 0; 5  8T : 8; 0; 0; 0  10T : 1; 0; 7; 2 | | 5T : 0; 1; 0; 1  8T : 1; 0; 0; 0  10T : 1; 0; 1; 1 | | 651.5745 | 5T : 1; 2; 6; 3  8T : 1; 2; 1; 3  10T : 5; 3; 1; 1 | | 5T : 3; 1; 1; 1  8T : 1; 1; 1; 1  10T : 1; 1; 3; 1 | | 0 | |
| Fleet Size Change | | 5T : 1; 1; 3; 0  8T : 4; 1; 1; 1  10T : 1; 1; 7; 1 | | 5T : 2; 1; 0; 1  8T : 1; 0; 0; 0  10T : 3; 5; 1; 5 | | 1850 | | 5T : 1; 0; 5; 4  8T : 4; 7; 0; 0  10T : 1; 0; 1; 5 | | 5T : 2; 6;1; 0  8T : 1; 1; 0; 0  10T : 3; 1;4; 1 | | 635.0877 | 5T : 1; 0; 5; 4  8T : 4; 7; 0; 0  10T : 1; 0; 1; 5 | | 5T : 2; 6;1; 0  8T : 1; 1; 0; 0  10T : 3; 1;4; 1 | | 0 | |
| Volume Change | | 5T : 1; 0; 0; 0  8T : 4; 4; 0; 0  10T : 0; 6; 1; 1 | | 5T : 7; 0; 0; 0  8T : 1; 0; 0.2349013E+08; 1  10T : 0; 1; 4; 5 | | 1689 | | 5T : 1; 2; 1; 1  8T : 1; 1; 0; 3  10T : 0; 2; 0; 6 | | 5T : 6; 4;0; 4  8T : 5; 1; 0; 1  10T : 0; 0; 4; 0 | | 659.1404 | 5T : 0; 0; 0; 1  8T :0; 9; 0; 0  10T: 9; 0; 1; 2 | | 5T : 1; 0; 0; 0  8T : 2; 0; 0; 5  10T: 1; 6; 2; 1 | | 0.97 | |
| Demand Change | | 5T : 1; 0; 0; 0  8T : 1; 3; 0; 0  10T : 7; 5; 2; 0 | | 5T : 2; 0; 1; 0  8T : 0; 3; 0; 0  10T :1; 0; 1; 0.1608060E+08 | | 1306 | | 5T : 2; 13; 1; 1  8T : 0; 0; 0; 0  10T : 7; 0; 2; 1 | | 5T : 1; 1; 0; 1  8T : 0; 0; 0; 0  10T : 1; 0; 1; 2 | | 498.8340 | 5T : 0; 0; 0; 1  8T : 0; 9; 0; 0  10T: 9; 0; 1; 2 | | 5T : 1; 1; 1; 1  8T : 1; 1; 1; 1  10T: 1; 4; 2; 1 | | 0 | |
| CO2 Adjusted Emission Factor | | 5T : 1; 1; 0; 1  8T : 4; 0; 1; 4  10T : 3; 1; 3; 1 | | 5T : 2; 1; 0; 1  8T : 1; 688205; 1; 1  10T : 1; 5; 2; 1 | | 1874 | | 5T : 0;1;1;4  8T : 1; 5; 1;2  10T : 1;0;0;1 | | 5T : 0; 3; 11; 1  8T : 1; 1; 1; 1  10T : 7; 0; 0; 1 | | 1424.979 | 5T : 3; 0; 8; 0  8T : 3; 2; 1; 0  10T : 0; 1; 0; 5 | | 5T : 3; 2; 1; 0  8T : 1; 1; 3; 0  10T : 0; 4; 0; 1 | | 1.859991 | |

Scenario: Truck Rental Change

With the reduction on the rental cost of 5 Tons trucks, the supplier should generally maximize on the 5 Tons trucks usage i.e. number of trucks by number of trips. The remaining auto-parts demand that cannot be fulfilled by the 5 Tons trucks are then delivered using either 8 Tons or 10 Tons trucks. However, the change amount might not be significant enough to cause a change in the allocation of supply among the different truck types given the two objectives.

Scenario: Fuel Surcharge Rate Change

With the reduction on the Fuel Surcharge Rate of 5 Tons trucks by 1.2% and an increase for both 8 Tons and 10 Tons truck, the supplier should maximize on the 5 Tons trucks usage i.e. number of trucks by number of trips, which offer benefits on the lower cost form both the truck rental and fuel usage for delivery. The remaining auto-parts demand that cannot be fulfilled by the 5 Tons trucks are then delivered using either 8 Tons or 10 Tons trucks.

Scenario: Fleet Size Change

With the reduction on the number of 5 Ton trucks and an increase in the 8 Ton truck, the supplier should still maximise on the 5 Tons truck usage. However, the remaining auto-parts demand should be allocated to the 8 Ton truck first where possible to benefit on the lower truck rental cost.

Scenario: Volume Change

With the increase in the capacity of 5 Tons truck by 3 cbm, the supplier should maximizes on the 5 Tons trucks usage i.e. number of trucks by number of trips, which offer benefits on the lower cost from both the truck rental with having higher delivery capacity. The remaining auto-parts demands that cannot be fulfilled by the 5 Tons trucks are then delivered using either 8 Tons or 10 Tons trucks. However, no optimal solution that meet both the objectives can be obtained as no supply can be delivered to assembly line 2. In other words, the demand constraint from assembly line 2 is not met.

Scenario: Demand Change

With an increase in demand from assembly line 1 and line 2 and a decrease in demand from assembly line 3 and 4, it is suggested that we arranged for bigger trucks to fulfil the increased load from line 1 and 2 rather than resort to using more 5 Ton truck.

Scenario: CO2 Adjusted Emission Factor

When there is a change in the carbon dioxide (CO2) adjusted emission factor, the bigger impact is on the carbon dioxide emission cost and not so significant on the transportation cost most of the time. It is probably also dependent on the importance of social corporate responsibility that the supplier has and the penalty cost arising from environmental policy. Technology breakthrough would probably also play a part in moderating the impact of this parameter.