Optimization of Sub route Logistics Network for a Manufacturing Supply chain

A global automobile manufacturing organization (Toyota) has its production base in the southern city of Bangalore, India. The company has 5 production plants that manufacturers the vehicle and the different units that are used to assemble the vehicle. The vehicles manufactured are primarily used for the domestic demand only, however some portion of the production is exported to countries in the African region. The two unit plants, TKAP and TIEI, has both domestic and export demand. The export demand for each of the unit plants are primarily for the different vehicle plants located in the ASEAN region.

The raw materials for the production of vehicle and the units are being supplied through three sources – Local parts (produced or sourced within India), or imports (sourced from Japan or from other countries such as Thailand, Indonesia. Within India, the majority of the local suppliers are distributed across the four major industrial belts namely – Delhi, Pune, Chennai and Bangalore region. Almost 85% of all suppliers are located in this belt, while the remaining 15% suppliers are located in other locations. The supplier locations naturally coincide with the automobile manufacturing hubs of India. Toyota is located in Bangalore where there are less OEM available and thus a limited supplier base.

The Logistics Network

Prior to 2016, each company followed an independent logistics system in which each company ordered to their supplier through their own systems and then transported the materials to Bangalore directly in their logistics network. The logistics system followed at Toyota uses the cross docking method as explained in the logistics model.

Each company operated their own logistics method. All companies have a common logistic partner (company name is TLI- transystem logistics). The general principle followed by all the plants are milk run method. Each company runs their own supply chain network and ordering system to best manage their operations KPI. Some of the major KPI to be followed in the supply chain across all companies is cost per unit (logistics transportation expense), inventory level inside (in terms of days of production), the frequency of logistics in main route, number of handling of parts in supply chain. Classical inventory ratios such as turnover ratios are not calculated here as the inventory levels are very low in the company (Lean systems followed). Here the key point to be noticed is that inventory levels are linked to logistics frequency.

Sl no	Frequency	Minimum Stock	Maximum stock
1	Daily Once	One day	2 days
2	Two day once	2 Days	4 Days
3	Three days once	3 Days	6 Days

The purchase agreement with suppliers from all the production plants are (within India) Ex works. This means supplier responsibility is to ensure that keep the parts ready in terms of quantity in the pre-described packaging condition as per the order shared by Toyota and it is responsibility of Toyota to pick it up from supplier gate and bring it up to the manufacturing plants in Bangalore.

Since suppliers are located primarily in 4 belts – Delhi, Pune, Chennai and Bangalore – for the plant, a cross docking method is followed for all outside regions away Bangalore region. Cross docks are warehouses where only parts storage and/or transfer happens. The parts are packed in the primary bin and secondary packing from the suppliers and shipped in sub route as per the Toyota schedules.

The movement of goods from the supplier till cross dock is called sub route. The sub route can be direct, milk run or supplier delivered. In direct, the vehicle arrange by Toyota goes and picks the parts from the supplier and comes to cross dock. In milk run, as the name suggest, the Toyota vehicle starts from the cross dock and then goes to a pre-defined list of suppliers and comes back to cross dock. Finally in the supplier delivered, the supplier is given the responsibility of delivery till cross dock at his vehicle or Toyota vehicle with the cost borne by supplier (This is a deviation from the ex-works logic, but only the delivery costs till dock is added to part cost – This method is usually used when suppliers are located in isolated locations and when supplier has a high frequent delivery to near cross dock area).

The main route is the movement of goods between dock and production plants (in Bangalore region suppliers to plant is also considered main route). The main route is usually maintained at high frequency low lot. This is mainly due to the fact that the inventory holding limits within the plants are limited (max space in vehicle plan is available for 4 hours and for unit plants for 1 day (excluding the minimum stock)). However the load available in each region is high enough to have multiple deliveries in a day depending on the truck type used.

The purpose of the cross-docking is to allow for splitting the frequency between sub-route and main route. The sub route usually follows high frequency low lot size but in practical situations it is tough to achieve this .This is because , some suppliers are located closely to each other that the high frequency is attainable but some suppliers maybe located far away that running high frequency may result in inefficient truck loading even with the smallest trucks selected. Also buying in a smaller truck for this purpose may result in having an investment locked into for the model life, which is again a loss for the organization. So based on the trade-off between the sub route truck type, sub route frequency , dock space available and the lead time , the adequate sub rote frequencies are decided. Some of the other rationale behind this is to optimize the supplier pick-ups with respect to logistics load. There are many conditions to be considered to split the frequency between main and sub route, such as, i) The main route truck is not able to go to the supplier premises (usually the main route truck will be bigger trailer trucks) ii) If daily supplier load is 1 box (as an example) and is located in an isolated location, then it is not feasible to send trucks daily to supplier for picking up the box rather it is better to send the vehicle in a lower frequency such as weekly once.

If there is a difference between the frequency of sub route and main route, then the difference in the lot size is maintained as inventory at the cross dock. At cross-dock, the right part, the right quantity at the right time is maintained to ensure on time arrival at the Toyota plants as the inventory are very low. It is important to note that there is no other inventory between Toyota plant and the cross dock, and the only inventory is what is contained inside the vehicles that moves between the dock and Toyota. This is one of the primary reasons why there is high frequency lot between dock and the production plan, and this high frequency provides a risk management support also (if one of the truck break-down or goes into accident, then the next truck is within 4 or 5 hours away, which is the stock maintained inside Toyota plants).

In Bangalore region, in the milk run method, the vehicles leave the plant and goes to different suppliers and pick up the orders sequentially and brings it back to the plant. The frequency of this milk-run can be from daily once to daily almost 32 times (every half hour once pick-up). The order to suppliers is also reflected with this frequency. The packing followed by all suppliers is euro packing methodology that allows different supplier packing to be stacked above or between each other. Also, the use of the all-side open vehicles in the supply chain allows for different suppliers to stack at different locations across the truck and also gives the freedom for the planner to modify the pick-up route sequence to best fit the operations.

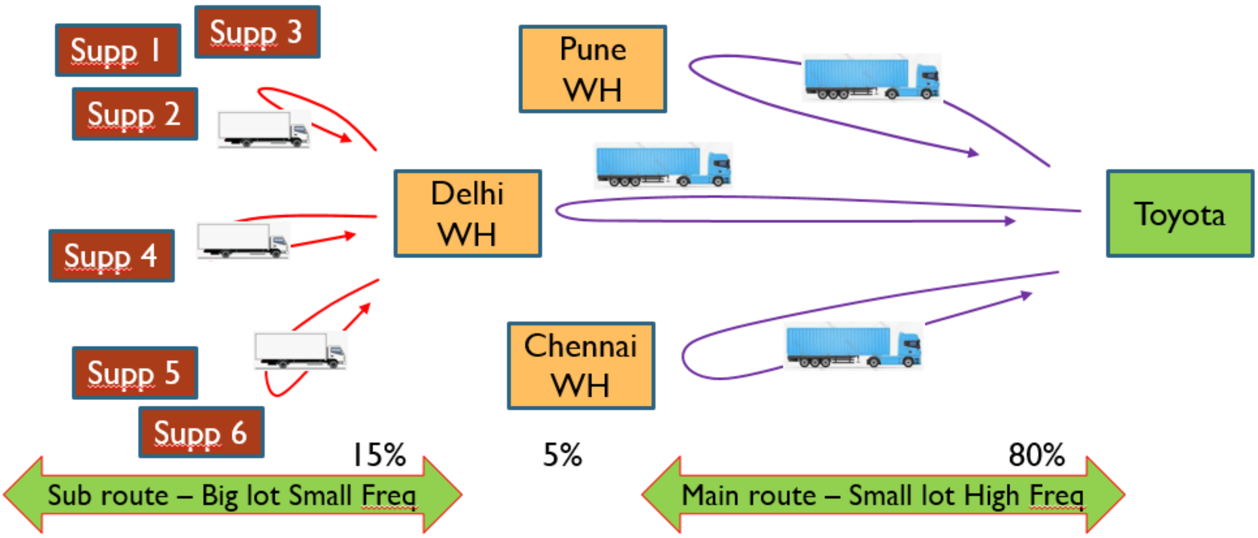

Image 1: A simple illustration of the logistics model followed in Toyota Supply Chain

Problem Statement

The objective of this project is to design a logistic network to collect all the supplier materials from supplier to Delhi Cross Dock at the minimum cost for TKAP. Some of the given conditions for the model is,

- 5 vehicles with different (Ton,M3) capacities : 1 x (14.5 , 37) + 4 x (7.6 , 37)
- 9 suppliers in Delhi region, and each supplier has a weekly ton and m3 demand.
- Truck can operate for 16 hours per day & 5 days a week with avg speed of 40 kmph

- Trip Cost consists of fixed component per hour, variable cost per km, and profit margins.

Initially in this model, we have tried with a smaller data set with 5 supplier and 3 trucks and then later once the model was fully developed the data was added with 9 suppliers and 5 trucks and the model was run to find the optimized output. The current model is made for TKAP Company and once this is done, and then can be used for the other companies as well.

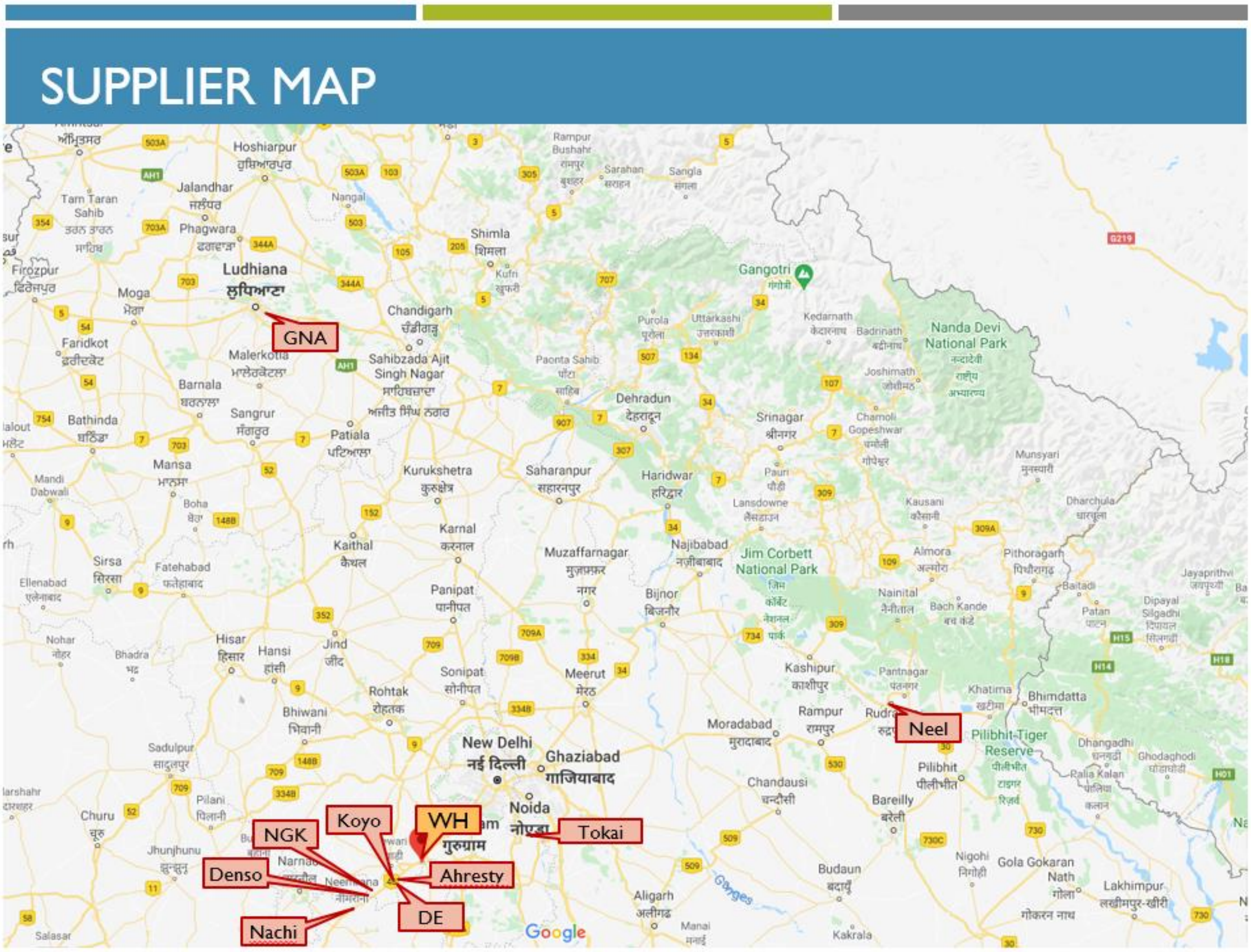

Image 2: The above image shows the map of the 9 suppliers of TKAP in Delhi Region.

Motivation for this project

- Usually Logistic Cost is around 2% of Product Price and usually in most companies this cost is usually ignored and not optimized. We usually assign a small percentage 3% to reduce annualy and this is assigned to planners who think very narrowly.
- Why Narrow? Manually making route combinations at Sub Route (4 Regions * 54 suppliers) + Main route (3 Routes * 5 Truck types) is really complex in excel & how to say it is optimized is a concern. Can optimize locally (maybe a zone of supplier in a region) but not globally (as a region).
- If we are able to get a 20% reduction in logistics costs through optimization then it can be converted to a direct 0.4% additional margins in Product price.

- Bring in a different thought process of problem solving (optimization) to organization & look at where all to implement across the company/ plant. The previous project on optimization of main route is partially responsible for creating a shared organization among 5 companies to optimize logistics.
- From an Industry perspective these kind of methods are not being practices much in the industry. The reason is these skilled people are not joining these but such innovations are driven by Startup such as rivigo etc. This project gives an opportunity to set an example.

Mathematical Model

- Data Set :
- N_suppliers : Number of suppliers (5 + 1 WH) # for actual it is made 9 + 1 WH
- N_trucks : Number of trucks in system (3) # for actual it is made 5
- N_property : Property of demand and truck load (as Tons and M3)
- N_trips : Number of trips in a week.
  - Trip is a truck round route from warehouse to supplier(s) to warehouse
- Index & Set
- i , j, h in set suppliers from 1 to N_Suppliers (i=j=h= 1 warehouse)
- t in set trucks from 1 to N_trucks
- d in set trips from 1 to N_trips
- p in property from 1 to N_property
- ARCS defined as arcs between supplier i and supplier j where i == j

Parameters:

- D_{ij} : Distance from supplier i to supplier j (where i=j= 1 is warehouse)
- FC_t : Fixed cost of using a truck defined as Rs/ hour for every truck t
- VC_t : Variable cost per km defined as Rs/km for every truck t
- S : Average speed of truck defined as 40 Kmph for all trucks
- RQ_{ip} : Weekly Requirement from each supplier i in terms of property p (tons, m3)
- C_{tp} : Capacity of truck t in terms of property p (tons, m3)
- Max_dist : Maximum distance a truck can do in a trip in a week = 3200 km
  - 16 hours/day * 5 days/week * 40 kmph
- Profit : 1. 1378 (as profit margins is 13.78 % including SGA)
- Teff : Max property of truck can be used = 1 (1 means 100% of ton or M3 capacity can be used)
- TC_d : Trip cost per trip defined as Rs/ trip used for every trip d (Rs 100 for toll charges)

Decision Variable :

- X_{ijdt} : Percentage of load of weekly requirement of supplier i moved from supplier i to supplier j in trip d on truck t
    - Defined only for i != j & lies between 0 and 1
- Y_{td} : is 1 if Truck t is used for trip d else 0 , defined over t and d
    - Defined as binary
- Z_{ijdt} : is 1 if X_{ijdt} is > 0 (if some load is moved from supplier i to j on truck t on trip d)
    - Defined only for i != j & binary
- R_{idt} : Rank of supplier i to be picked up on truck t on trip d (Reference Milk Collection problem)
- Supporting variables to calculate KPIs
    - $truckeff_{dt}$: Efficiency of truck t on trip d
    - $suppload_{ip}$: Total load of supplier i carried over the week in terms of property p (Ton / M3)

Objective function :

Minimize (A + B + C) * Profit

- **Variable Costs**
    - B = $\sum_{i=1}^{N\_suppliers} \sum_{j=1}^{N\_suppliers} \sum_{d=1}^{N\_trips} \sum_{t=1}^{N\_trucks} (Z_{ijdt} * D_{ij} * VC_t) \; for \; all \; i,j,d,t$
    - We calculate total distance travelled in each trip and then multiplied with the variable cost
- **Fixed Costs**
    - A=$\sum_{i=1}^{N\_suppliers} \sum_{j=1}^{N\_suppliers} \sum_{d=1}^{N\_trips} \sum_{t=1}^{N\_trucks} ((Z_{ijdt} * D_{ij}) / S) * FC_t \; for \; all \; i,j,d,t$
    - We calculate total distance travelled in each trip and then converted into hours using avg speed & multiplied with the fixed cost per hour
- **Trips Costs**
    - C = $\sum_{d=1}^{N\_trips} \sum_{t=1}^{N\_trucks} \left(Y_{td} * TC_d \right) for \; all \; d,t$

Constraints

- #0 → X is 0 when i = j
    - $X_{ijdt} = 0 \; \forall \; i,j,d,t$ for every i = j
- #1 → Y is 1, if any X in the trip d and truck t is > 0
    - $Y_{dt} \geq X_{ijdt} \; \forall \; i,j,d,t$

- #2 → Z is 1 if any X in the trip d and truck t is > 0
  - $Z_{ijdt} \geq X_{ijdt} \; \forall \; i, j, d, t$
- #3 → Total % load taken from supplier i across all trips d and truck t is >= 1
  - $\sum_j \sum_d \sum_t X_{ijdt} \geq 1 \; \forall \; i$
- #4 → Total load carried in truck t on trip d should be within the truck property p capacity
  - $\sum_i (\sum_j X_{ijdt} * RQ_{ip}) \leq teff * C_{tp} \; \forall \; d, t, p$
- #5 → For any truck t, distance covered should not run more than max km in a week.
  - $\sum_i \sum_j \sum_d Z_{ijdt} * D_{ij} \leq \text{Max\_dist} \; \forall \; t$
- #6 → sub tour elimination in each day d and truck t. Cannot go to supplier with lower rank
  - $R_{jdt} \geq R_{idt} + 1 - \text{N\_suppliers} * \left(1 - Z_{ijdt}\right) \; \forall \; (i, j \geq 2), d, t$
- #7 → R initiation i.e. Rank of supplier 1 is set as 1 for all day d and truck t
  - $R_{1dt} = 1 \; \forall \; d, t$
- #8 → Any truck t starts from warehouse for any trip d
  - $\sum_j Z_{ijdt} = 1 \; \forall \; i = 1, \; d, t$
- #9 → Balancing constraint (from reference 2) for every supplier h except warehouse, incoming leg is equal to outgoing legs (whatever comes in goes out)
  - $\sum_i Z_{ihdt} = \sum_j Z_{hjdt} \; \forall \; d, t, h! = 1$

Display variables (to show some derived KPIs)

- #10 → Truck efficiencies is less than/equal to maximum allowed trick efficiency i.e. 100%
  - $\sum_i \sum_j X_{ijdt} * RQ_{ip} / C_{tp} <= \text{truckeff}_{dt} \; \forall \; d, t, p$
- #11 → load % from supplier for all days and for all trucks should sum up to the amount of demand of a supplier fulfilled in all trips and by all trucks
  - $\sum_j \sum_d \sum_t X_{ijdt} * R_{ip} <= \text{Suppload}ip \; \forall \; i, p$ (The detailed explanation is given along with the model in the AMPL Model – in the appendix)

Data Sets

Distance Matrix										
	WH	GNA	Neel	Koyo	Nachi	Denso	Tokai	NGK	Ahresty	DE
WH	0	419	310	25	49	26	59	26	25	25
GNA	419	0	592	445	483	413	421	458	456	455
Neel Metal	310	592	0	335	358	288	278	335	333	333
Koyo	25	445	335	0	30	51	113	7	3.9	3
Nachi	49	483	358	30	0	75	136	30	28	27
Denso	26	413	288	51	75	0	80	52	49	49
Tokai Imperial	59	421	278	113	136	80	0	112	146	145
NGK	26	458	335	7	30	52	112	0	4.7	5
Ahresty	25	456	333	3.9	28	49	146	4.7	0	1.6
Diamond Electric	25	455	333	3	27	49	145	5	1.6	0

Image 3: Distance matrix between suppliers

Truck Availability and capacities			
Parameter	Ton	M3	Nos
Truck LDD	14.5	37	1
HCV	7.6	37	4

Image 4: Number of trucks in the system its capacities

Costs related to trucks		
Truck Type	Fixed	Variable
LDD	542	32
HCV	577	28

Image 5: The fixed and variable costs for each truck type

Supplier Demnd for a week		
	Tons	M3
GNA	33.88	27.5
Neel Metal	10	25
Koyo	3.5	10
Nachi	7.9	11.25
Denso	0.75	5
Tokai Imperial	0.4	1.25
NGK	1.75	5
Ahresty	2.8	40
Diamond Electric	1.25	5;

Image 6: For each supplier we can see the weekly demand in terms of tons and m3

Output Result

Here we can see the model output for the pilot model

OUTPUT – PILOT MODEL ~ SUPP 5 + TRUCK 3

- Run time : 8.95446 s
- Trucks Used : 2/3 Used
- # Trips : 5 TRIPS IN A WEEK

Trip	Route	Truck	Dist.	Time	Efficiency
1	WH → GNA → WH	LDD	838	23.9	100 %
2	WH → NEEL → DENSO → WH	LDD	624	17.9	82
3	WH → GNA → WH	HCV	838	23.9	100
4	WH → NACHI → KOYO → WH	LDD	104	2.98	79
5	WH → GNA → WH	LDD	838	23.9	100

- Net Supplier % Load

Supp	GNA	NEEL	DENSO	NACHI	KOYO				
% Week	108%	100	100	100	100				

- TOTAL COSTS : RS 1,72,871 / MONTH
  - Fixed : 51042 ; Variable : 100392 ; Trip costs: 500; Profits+ SGA : 20927

Here the below model shows the output for the total model

OUTPUT – PILOT MODEL ~ SUPP 9 + TRUCK 5

- Run time : 116692 s
- Trucks Used : 3/5 Used
- # Trips : 6 TRIPS IN A WEEK

Trip	Route	Truck	Dist.	Time	Efficiency
1	WH → GNA → WH	LDD	838	23.9	100 %
2	WH → NGK → AHRESTY → KOYO	HCV	60	1.7	100
3	WH → AHRESTY → DE → NACHI	LDD	102.6	2.9	100
4	WH → GNA → WH	HCV	838	23.9	100
5	WH → DENSO → NEEL → TOKAI → WH	LDD	651	18.6	85
6	WH → GNA → WH	LDD	838	23.9	100

- Net Supplier % Load

Supp	GNA	NEEL	KOYO	NACHI	DENSO	TOKAI	NGK	AHRESTY	DE
% Week	108%	100	100	100	100	100	100	106.7	100

- TOTAL COSTS : RS 1,77,385 / MONTH
  - Fixed : 52421 ; Variable : 102880 ; Trip costs: 600; Profits+SGA : 21483

Then we can see actual condition & then we are comparing actual condition with model output

OUTPUT – ACTUAL CONDITION ~ SUPP 9 + TRUCK 5

- Trucks Used : 5 Used
- # Trips : 9 TRIPS IN A WEEK

Trip	Route	Truck	Dist.	Time	Efficiency
1	WH → GNA → WH	LDD	838	23.9	100 %
2	WH → GNA → WH	LDD	838	23.9	100 %
3	WH → GNA → WH	LDD	838	23.9	60 %
4	WH → NEEL → WH	HCV	620	17.8	100 %
5	WH → NEEL → WH	HCV	620	17.8	80 %
6	WH → NACHI → NGK → WH	HCV	160	4.6	100
7	WH → AHRESTY → KOYO → DE → WH	HCV	55	1.6	75
8	WH → AHRESTY → NACHI → WH	HCV	50	1.4	81
9	WH → DENSO → TOKAI → WH	HCV	21	0.8	56

- Net Supplier % Load

Supp	GNA	NEEL	KOYO	NACHI	DENSO	TOKAI	NGK	AHRESTY	DE
% Week	100%	100	100	100	100	100	100	100	100

- TOTAL COSTS : RS 2,19,153 / MONTH

COMPARISON WITH ACTUAL CONDITION (BENEFIT ANALYSIS)

Parameter	Current Condition	Model	Benefits
Suppliers + Trucks	9+5	9+5	
Trucks Used	5	3	2 Truck Investment
Trips / Week	9	6	3 Trips
Distance – Km	4040	3327	713 Km
Emission – Tons/Wk	3.6	2.9	- 20%
Expense – Rs/ Wk	219153	177385	-19%
Truck Eff – Low%	56%	85%	+29%

Assumptions used in the Model

- Supplier Loading/ unloading times not considered in the model (30 mins/supplier)
- Total requirement of a week is considered to come 1 week before requirement
- Scheduling of trips in a week is not considered here (which trip on which day)
- Max usable efficiency of trucks is assumed at 100% (but actually it is kept at 98% ~ This is made as a parameter and can be varied directly)
- Average Truck speed depends on traffic and time conditions, so we maintained a constant parameter for average speed in the model
- Distance matrix is made using google maps, but however actual routes may depend on the route being available for movement of trucks
- Supplier Loading/ unloading times not considered in the model (30 mins/supplier)

Learnings from group project

- Rather than optimizing available resources, there is an opportunity to study how many resources is required in the system.
- How to have a bigger perspective and look at the problem from third person. Then start to building model by gradually adding constraints.
- How to measure KPIs in the model and understand how much in-efficiency is there in the system and thus how to look back at putting in the right resources
- How to model a practical problem mathematically and subsequently in AMPL
- Levelled up skills in AMPL modelling
- The advantage of scalability when the region expands or more companies' load are grouped for optimization

SUMMARY

From this model we can see that there is a potential benefit in terms of cost and environment. However there are some assumptions we have made in this model to make the model closer to the actual condition. However these assumptions can then be modelled into our model. Actual implementation requires the additional investment in terms of the software and then the returns associated needs to be offset with the benefits also.

REFERENCES

1. Class Lecture notes
2. Route design for lean production systems by Jeffrey W Ohlmann, Michael J Fry, and Barrett W Thomas.
3. The two period travelling salesman problem applied to milk collection in Ireland by Martin Butler, H Paul Williams, Leslie Ann Yarrow

APPENDIX

Model

```
param n_suppliers;
param n_trucks; #1 LDD and 5 HCV
param n_property; # wt and volume for supplier and truck
param n_trips; # number of trips

# all sets definition
set suppliers:= 1..n_suppliers;
set trips:=1..n_trips;
set truck:=1..n_trucks;
set property := 1..n_property;
set ARCS := {i in suppliers, j in suppliers : i == j} ;

#parameters definition
param distance {suppliers,suppliers};
param FCT {truck};
param VC {truck};
param S;
param demand {suppliers,property};
param teff;
param capacity {truck,property};
param tripCost {trips};
param max_dist;
param profit;


#Variables definition
var X{suppliers,suppliers,trips,truck} >= 0 <=1 ; #%(decimal between 0 and 1 of load
from supplier to supplier in trip d in truck t
var Y{trips,truck} binary ; #to caputure if truck t is run in trip d if X >0
var Z{suppliers,suppliers,trips,truck} binary ; #indicate movement from supplier to
supplier on trip d in truck t
var R{suppliers,trips,truck} >=0 integer ; # rank of supplier in trip d for a truck t

#These variables are only for ease of visualization and calculation
var truckeff{trips,truck} ; # efficiency of supplier in trip d for a truck t
var suppload{suppliers,property};# load from a supplier s in terms or property p
var A; #Distance wise truck maintainance cost
var B; #variable costs

#objective function
minimize total_costs : ( (sum {d in trips, t in truck}  tripCost[d]*Y[d,t]) + A + B ) *
profit ;

#constraints
subject to

#0 X is 0 when i == j , no load from supplier i to j when i == j
const_0 {(i,j) in ARCS, d in trips, t in truck} : X[i,j,d,t] = 0 ;

#1 Y to be made 1 if any X > 0
const_1 {i in suppliers,j in suppliers, d in trips, t in truck} : Y[d,t] >= X[i,j,d,t] ;

#2 Z to be made 1 if any X > 0
const_2 {i in suppliers,j in suppliers, d in trips, t in truck } : Z[i,j,d,t] >=
X[i,j,d,t] ;
```

```
#3 For all suppliers i , total percentage of load for supplier i for a week should be >=
1
const_3 {i in suppliers} : sum{j in suppliers, d in trips, t in truck} X[i,j,d,t] >= 1 ;

#4 The capacity of truck occupied by all suppliers (to all other suppliers) in a trip
should
#be less than equal to total capacity of property p for every d in trips and truck t
const_4 {d in trips, t in truck, p in property} : sum{i in suppliers} ( sum{ j in
suppliers } X[i,j,d,t] * demand[i,p] ) <= teff * capacity[t,p] ;

#5 truck should not run more than max km in a week.
const_5 {t in truck} : sum { i in suppliers,j in suppliers, d in trips } Z[i,j,d,t] *
distance[i,j] <= max_dist ;

#6 sub tour elimination in each trip d and truck t
# such if there is a path from supplier i to j, the rank of j is greater than i
const_6 {i in suppliers,j in suppliers, d in trips, t in truck : j >= 2} : R[j,d,t] >=
R[i,d,t] + 1 - n_suppliers * ( 1 - Z[i,j,d,t] ) ;

#7 Rank R initialization for every trip in d and truck in t
const_7 {d in trips , t in truck} : R[1,d,t] = 1 ;

#8 vehicle moves from the warehouse , therefore Z [i,j,d,t] where i == 1 should always
be true
const_8 {i in suppliers , d in trips ,  t in truck : i = 1} : sum{j in suppliers}
Z[i,j,d,t] = 1 ;

#9 Balancing constraint (from reference 2) for every supplier h except warehouse,  from
how many suppliers h is visited,
# so many times from h to other supplier is visited (whatever comes in goes out)
const_9 {h in suppliers, d in trips, t in truck : h != 1} : sum{i in suppliers}
Z[i,h,d,t] = sum{j in suppliers} Z[h,j,d,t] ;

#Below constraints is to show the some calculated variables from the model

#1 show truck efficiencies (max % of each property p) for every truck t and trip d
show_1 { d in trips, t in truck, p in property} : sum{i in suppliers , j in suppliers}
X[i,j,d,t] * demand[i,p] / capacity[t,p] <= truckeff[d,t] ;

#2 The suppload[i,p] is equal to the amount of demand of supplier i that is fullfilled
by
# movement of load from i to all suppliers j in all trips d in all trucks t
show_2 {i in suppliers, p in property} : sum{j in suppliers, d in trips,t in truck}
X[i,j,d,t] * demand[i,p]  <= suppload[i,p] ;

#3 The cost A is net fixed cost related to all trucks used in all trips
# (The total distance is calculated for each trip d and truck t, and then divided by the
average speed to get total hour/trip
# Each hour per trip has a fixed cost related which is multiplied.
show_3 : sum {i in suppliers,j in suppliers,d in trips, t in truck} Z[i,j,d,t] *
distance[i,j] * FCT[t] / S = A ;

# 4The cost B total of is the variable cost of truck t in all trips covering all the
distacnes
#between supplier i and supplier j, which is calculated by multiplying the cost of
running truck
#t per km and the distance covered from all suppliers i to all suppliers j.
```

```
show_4 : sum {i in suppliers,j in suppliers, d in trips, t in truck} VC[t] * Z[i,j,d,t] *
distance[i,j] = B;
```

Data set for Pilot Model (5 suppliers and 3 trucks)

```
param n_suppliers:=6;
param n_trucks:=3; #1 LDD and 5 HCV
param n_property:= 2; # wt and volume
param n_trips:= 5; # number of trips in week

param distance:
       1      2      3      4      5      6:=
1      0      419    310    25     49     26
2      419    0      592    445    483    413
3      310    592    0      335    358    288
4      25     445    335    0      30     51
5      49     483    358    30     0      75
6      26     413    288    51     75     0;

#Rs/truck/hour= for 6 trucks
param FCT:=
1      542
2      577
3      577;

#Rs/km for each type of truck (incl km and toll charges average at 3/km
param VC :=
1      32
2      28
3      28;


#average speed of truck in kmph
param S := 35 ;

#demand is defined over suppliers & wt/wol per week
param demand:
       1      2:=
1      0      0
2      33.88  27.5
3      10     25
4      3.5    10
5      7.9    11.25
6      0.75   5;


#how much of truck capacity can be used
param teff:= 1;

#truck capacity in terms of trucks and wt / vol
param capacity:
       1      2:=
1      14.5   37
2      7.6    37
3      7.6    37;

#These costs represents the toll cost for each trip
param tripCost :=
1 100
2 100
```

```
3 100
4 100
5 100;

#max distance travelled by any truck in a wekek = 16*5*40 = 3200 km per week
param max_dist:= 3200;

#Profit margin is at 13.78%
param profit:= 1.1378;
```

Data set for Actual Model (9 suppliers and 5 trucks)

```
param n_suppliers:=10;
param n_trucks:=5; #1 LDD and 5 HCV
param n_property:= 2; # wt and volume
param n_trips:= 5; # five days of week

param distance:
        1       2       3       4       5       6       7       8       9       10:=
1       0       419     310     25      49      26      59      26      25      25
2       419     0       592     445     483     413     421     458     456     455
3       310     592     0       335     358     288     278     335     333     333
4       25      445     335     0       30      51      113     7       3.9     3
5       49      483     358     30      0       75      136     30      28      27
6       26      413     288     51      75      0       80      52      49      49
7       59      421     278     113     136     80      0       112     146     145
8       26      458     335     7       30      52      112     0       4.7     5
9       25      456     333     3.9     28      49      146     4.7     0       1.6
10      25      455     333     3       27      49      145     5       1.6     0;

#Rs/truck/hour= for 6 trucks
param FCT:=
1       542
2       577
3       577
4       577
5       577;

#Rs/km for each type of truck (incl km and toll charges average at 3/km
param VC :=
1       32
2       28
3       28
4       28
5       28;


#average speed of truck in kmph
param S := 35 ;

#demand is defined over suppliers & wt/wol per week
param demand:
        1       2:=
1       0       0
2       33.88   27.5
3       10      25
4       3.5     10
5       7.9     11.25
6       0.75    5
7       0.4     1.25
```

```
8       1.75   5
9       2.8    40
10      1.25   5;


#how much of truck capacity can be used
param teff:= 1;

#truck capacity in terms of trucks and wt / vol
param capacity:
        1      2:=
1       14.5   37
2       7.6    37
3       7.6    37
4       7.6    37
5       7.6    37;

param tripCost :=
1 100
2 100
3 100
4 100
5 100;

#max distance travelled by any truck in a wekek = 16*5*40 = 3200 km per week
param max_dist:= 3200;
```

Run File

```
reset;

# For 6_3 Model

model Final.mod;
data 6-3.dat;
option solver CPLEX;
#option solver cplexamp;

#option cplex_options 'mipdisplay=4 mipinterval=4';#How to display solver statistics(Useful later with Integer variables)

solve;
show > 6-3.txt;
display _total_solve_time >  6-3.txt;
display total_costs>6-3.txt;
display Z>6-3.txt;
display X>6-3.txt;
display Y>6-3.txt;
display R>6-3.txt;
display truckeff>6-3.txt;
display suppload>6-3.txt;
display A>6-3.txt;
display B>6-3.txt;

expand>6-3.txt;
close 6-3.txt;

# For 6_5 Model
```

```
#model Final.mod;
#data 6_5.dat;
#option solver CPLEX;
#option solver cplexamp;
#option cplex_options 'mipdisplay=6.5 mipinterval=6.5';#How to display solver
statistics(Useful later with Integer variables)

#solve;
#show > 6_5.txt;
#display _total_solve_time >  6_5.txt;
#display total_costs>6_5.txt;
#display Z>6_5.txt;
#display X>6_5.txt;
#display Y>6_5.txt;
#display R>6_5.txt;
#display truckeff>6_5.txt;
#display suppload>6_5.txt;
#display A>6_5.txt;
#display B>6_5.txt;

#expand>6_5.txt;
#close 6_5.txt;
```

Output file for 5 Supplier and 3 Trucks is in the txt file as the output is really long

Output file for 9 Supplier and 5 Trucks is in the txt file as the output is really long

---