Designing and Operating Domestic Milk Run and Order Consolidation in China

Department of Industrial Systems Engineering and Management | IE3100R Systems Design Project

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Overview

Project Description: This project aims to improve the logistical operational efficiency of DHL in China by developing a software. The company is required to collect products from small volume suppliers and send them to "Consolidation Centres "(CC) before they are shipped to overseas plants. There are currently about 180 suppliers and 4 CCs in China and about 12 plant locations. The number of CCs may subject to change based on the production and shipment volumes.
Our software will assist DHL to plan order consolidation and design milk run routes at a tactical (quarterly master routing) and operational (daily to weekly planning) level.

Software Specifications

- Free
- Easy to Learn
- Fast
- Close to Optimum

Methodology

Identification of client requirement → Data collection & cleansing → Proposed solution → Result evaluation → Feedback collection → Modification & final launch

Proposed Solution

Client Requirement

- Able to determine the optimal number of CCs in service and assign suppliers accordingly
- Able to generate a near-optimal milk run routing according to customers' location, demand weight, shipment cost, etc.

Solution

- ✓ Use Least Cost Method to allocate suppliers to the most appropriate CC
- ✓ Use Savings Heuristics to allocate suppliers different routes and apply Cheapest Insertion Method to arrange their sequence in the route

First step is to decide the assignment of Consolidation Centres to all the customers → Assign customers to their nearest Consolidation Centre (Out of 6 options: Tianjin, Dalian, Shenzhen, Xiamen. Shanghai and Qingdao) → Based on customers' respective final destination, the volume of each CC-Destination route can be obtained → Shut down the CC-Destination route if the volume is less than 30 cbm (the threshold volume is subject to change for users) → Check the number of CC-Destination routes for each CC, shut down the CC if there is no route → Repeat the above steps until there is no more shutting down of Consolidation Centres. As a result, each customer is assigned to one Consolidation Centre → The program proceeds to decide milk run routes (using a Saving Heuristic).

Start by assigning each customer with a single vehicle that has the smallest capacity to service its demand. Each customer forms a subtour → There is a total saving resulting from combining two customers into one route → Enumerate all possible combinations of the customers to find the one with largest saving and combine them into one route → Add the new route to the to the list of customers → The program then proceeds to decide the sequence of pick-up from customers in the same route (using a Cheapest Insertion Method) → Recursively traverse the whole list and repeat the previous steps until all demands are fulfilled. In this way, each customer is in one route (route size >= 1) → Final output of the program are the sequenced routes for all Consolidation Centres from Week 1 to 4

Mathematical Model

In order to ensure the solution obtained is within an acceptable range, we compare our route generation results with an optimized solution computed by Cplex. We formulate the problem as a Fleet Size and Mix Vehicle Routing Problem (FSMVRP). Mathematically, the problem is represented as:

Let $G = (N, A)$ be a directed graph with the set A of directed arcs, and the set N of nodes representing a central depot and suppliers.

N Suppliers are indexed from 1 to n while the index 0 denotes the CC
d_i known demand for Supplier i, $i \in N\backslash\{0\}$
K types of vehicles, with $K = \{1, \dots, 7\}$ denoting the set of such types
Q_k capacity of vehicle type K
f_k fixed cost of vehicle of type $k \in K$

$$c_{ij}^k \begin{cases} \text{The cost of a vehicle of type k} \in \text{K traversing arc } (i,j) \in A & \\ 50 & if\ i \in N\backslash\{0\},\ j \in N\backslash\{0\}, i \neq j \\ 0 & if\ \ i \in \{0\},\ j \in \{0\}, i = j \end{cases}$$

$$x_{ij}^k \begin{cases} 1\ if\ vehicle\ of\ type\ k\ visits\ from\ supplier\ i\ to\ j \\ 0 \qquad otherwise \end{cases}$$

y_{ij} flow of goods from i to j

$$\min \sum_{k\in K} f_k \sum_{j\in N} x_{0j}^k + \sum_{k\in K}\sum_{i\in N}\sum_{j\in N} c_{ij}^k x_{ij}^k \quad (1)$$

$$s.t.$$

$$\sum_{k\in K}\sum_{i\in N} x_{ij}^k = 1 \qquad \forall j \in N\backslash\{0\} \quad (2)$$

$$\sum_{i\in N} x_{ij}^k - \sum_{i\in N} x_{ji}^k = 0 \qquad \forall j \in N\backslash\{0\},\ k \in K \quad (3)$$

$$\sum_{j\in N}\sum_{i\in N} x_{ij}^k \leq |N| - 1 \qquad \forall k \in K \quad (4)$$

$$\sum_{i\in N} y_{ji} - \sum_{i\in N} y_{ij} = d_j \qquad \forall j \in N\backslash\{0\} \quad (5)$$

$$y_{0j} \leq \sum_{k\in K} Q_k x_{0j}^k \qquad \forall j \in N\backslash\{0\} \quad (6)$$

$$y_{ij} \leq M \sum_{k\in K} x_{ij}^k \qquad \forall i \neq j \in N\backslash\{0\} \quad (7)$$

$$x_{ij}^k \in \{0,1\} \qquad \forall i \neq j \in N\backslash\{0\}, \forall k \in K \quad (8)$$

$$y_{ij} \geq 0 \qquad \forall i \neq j \in N\backslash\{0\} \quad (9)$$

Performance Evaluation

- ❖ Five sets of randomized sample models of 10, 15 and 20 suppliers with one CC were developed respectively and tested independently to measure the efficiency. Results are summarized in the table to the right.
- ❖ In general, the solution obtained from heuristics were close to the optimal solutions. The gap in total cost was less than 5 % up to 20 suppliers, which is within a reasonable range. The computational time was also significantly less the Cplex solution.

	10 Suppliers			
	CPLEX Cost Based	Excel Tool Savings Heuristics	Analysis	
Input	Computational time (s)	Computational time(s)	Gap in total cost in %	Reduction in time in %
1	0.13	0.08	1.37%	38.46%
2	0.65	0.1	3.22%	84.62%
3	0.34	0.05	0.26%	85.29%
4	0.68	0.09	3.63%	86.76%
5	0.49	0.09	0.13%	81.63%
Average	0.458	0.082	1.72%	75.35%

	15 Suppliers			
	CPLEX Cost Based	Excel Tool Savings Heuristics	Analysis	
Input	Computational time (s)	Computational time(s)	Gap in total cost in %	Reduction in time in %
1	40.73	0.12	4.74%	99.71%
2	0.2	0.15	4.64%	25.00%
3	0.68	0.16	5.29%	76.47%
4	0.79	0.15	1.00%	81.01%
5	7.31	0.16	0.79%	97.81%
Average	9.942	0.148	3.29%	98.51%

	20 Suppliers			
	CPLEX Cost Based	Excel Tool Savings Heuristics	Analysis	
Input	Computational time (s)	Computational time(s)	Gap in total cost in %	Reduction in time in %
1	991.18	0.22	5.60%	99.98%
2	803.71	0.18	0.31%	99.98%
3	524.93	0.17	5.83%	99.97%
4	1167.04	0.19	1.15%	99.98%
5	1298.31	0.22	4.89%	99.98%
Average	957.034	0.196	3.56%	99.98%

Final Product

Given the required specifications, we used Microsoft Excel to develop our software. We coded our proposed solution heuristics using VBA and developed the interface using macros.

S/N	Supplier	Weight (ton)	Latitude (N)	Longitude (E)	Supplier City	Shipment Frequency	Destination	Volume (cbm)
1	Supplier 1	23	32.175914	119.497233	City A	Weekly	Plant 1	0.02
2	Supplier 2	23	32.175914	119.497233	City A	Fortnightly	Plant 2	0.03
3	Supplier 3	11	32.175914	119.497256	City A	Weekly	Plant 3	0.888
4	Supplier 4	15	32.18095	119.506396	City B	Monthly	Plant 4	0.0016
5	Supplier 5	30	23.044837	113.770688	City C	Weekly	Plant 5	3.48
6	Supplier 6	7	39.908936	119.548857	City D	Monthly	Plant 6	0.0125
7	Supplier 7	60	31.488315	121.142151	City E	Weekly	Plant 7	30.52
8	Supplier 8	8	31.488315	121.142151	City E	Fortnightly	Plant 5	1.11
9	Supplier 9	1.2	31.488315	121.142151	City E	Fortnightly	Plant 2	39.42

Before starting the program, users are required to prepare a list of information as shown.

CC Assigned	Zone	Week of Delivery	FCL	Weekly Volume
Shanghai	1	1		0.016201982
Shanghai	1	2		0.01280125
Shanghai	1	3		0.888309639
Shanghai	1	4		0.000403099
Xiamen	0	1		3.684262222
Shanghai	12	4		0.0031125
FCL	0	1	CL	30.51657316
Shanghai	9	2		0.555289778
FCL	0	2	CL	19.70823556

CC	Latitude (° N)	Longitude (° E)	Count	Total Volume	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6
Shanghai	30.922	121.885	58	8.687319752	6.352827	0.0128012	0.88831	0.324516	0.85529	0.0031
Dalian	38.934	121.664	0	0	0	0	0	0	0	0
Tianjin	38.975	117.741	1	0	0	0	0	0	0	0
Qingdao	36.064	120.338	0	0	0	0	0	0	0	0
Shenzhen	22.574	114.271	3	0	0	0	0	0	0	0
Xiamen	24.441	118.157	1	3.684262222	0	0	0	0	0.684262	0

CC	Latitude (° N)	Longitude (° E)	Count	OPEN/CLOSED	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6
Shanghai	30.922	121.885	58	1	1	1	1	1	1	1
Dalian	38.934	121.664	0	1	0	0	0	0	1	0
Tianjin	38.975	117.741	1	1	1	0	0	0	0	0
Qingdao	36.064	120.335	0	1	0	0	0	0	0	0
Shenzhen	22.574	114.271	3	1	1	0	0	0	0	0
Xiamen	24.441	118.157	1	1	1	0	0	0	1	0
				closed : 0						

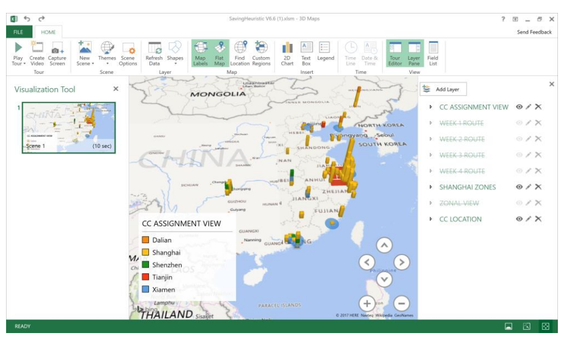
Input Parameters
Minimum volume per destination/CC (CBM)

After clicking "Assign CC" button, the consolidation plan will be displayed. The program will indicate which CC the suppliers are assigned to and the total volume consolidated at each CC. Suppliers with Full Container Load (FCL) will be highlighted and excluded from the next stage of planning.

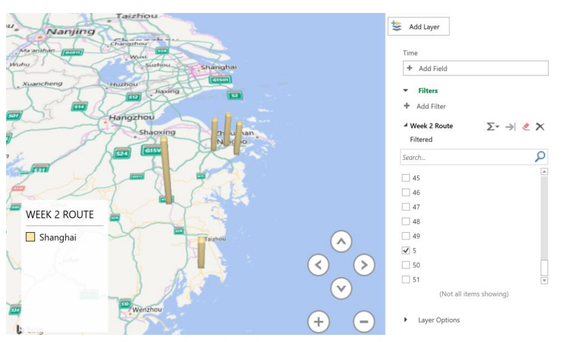
	Consolidation Centre	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5	Supplier 6
Time		Day 1 8am-11am	Day 1 11am-1pm	Day 1 1pm-3pm	Day 1 3pm-5pm	Day 2 8am-11am	Day 2 11am-1pm
Route 1	Shanghai	Supplier AAA [City A]	Supplier BBB [City B]				
Route 2	Qingdao	Supplier CCC [City C]	Supplier DDD [City C]	Supplier EEE [City D]	Supplier FFF [City E]	Supplier GGG [City E]	Supplier HHH [City F]
Route 3	Xiamen	Supplier III [City X]	Supplier JJJ [City Y]	Supplier KKK [City Z]			
Route 4	Shenzhen	Supplier ABC [City M]					

After clicking the "Get Result" button, the program will generate the final weekly milk run routing for the planning horizon of one month.

Our Excel software is also able to visualize CC route allocation for different suppliers. We use Excel PowerMap to generate this visualization. This map is also useful in ensuring the credibility of the solution generated by our software.



Suppliers colour coded based on CC allocation



Route visualization for a certain week

*Data presented on this poster are fabricated for demonstration purpose only