**MATHEMATICAL MODEL TWO ECHELON VEHICLE ROUTING PROBLEM**

**1.1 Sets and indices**

Set of depots

Set of satellites

Set of customers

Set of nodes for 1st echelon

Set of nodes for 2nd echelon

Set of all nodes

Set of arcs   
Set of vessels

Set of cargo bikes

Set of vehicles

**1.2 Parameters**

Costs/distance between location i and location j

Service time at location i Demand per customer

**1.3 Decision variables**

The route of the truck from location i to j, 1 = arc, 0 = no arc

Time counter of elapsed time at the arrival of location i

Load counter after delivery at location i

**1.4 Objective function (minimizing the total distance)**

Total distances travelled

**1.5 Constraints**

First echelon:

M times number of incoming arcs at hub must be greater or equal to outgoing arcs at hub

Making sure the vessel does not stay at the same location

The sum of outgoing arcs is equal to the sum of incoming arcs

Each vessel departs from the depot only once

The timer at i plus the costs between i and j plus the service time at i is smaller or same as the timer at j

The load after delivery at i minus the demand of j is greater or same as the load after delivery at j

The load after delivery at i plus the demand of customer i is smaller or same as the capacity

Second echelon:

The sum of every row and column in the route variable x is equal to 1

Making sure the cargo bike does not stay at the same location

The sum of outgoing arcs is equal to the sum of incoming arcs

Each cargo bike departs from the satellites only once

The timer at i plus the costs between i and j plus the service time at i is smaller or same as the timer at j

The load after delivery at i minus the demand of j is greater or same as the load after delivery at j

The load after delivery at i plus the demand of customer i is smaller or same as the capacity