**Mathematical Model: -**

|  |
| --- |
| Customer subgroup index, j=1..........J |
| Manufacturer (Mfr) index, m=1..........M |
| SVS index, s=1..........S (State Vaccine Store) |
| RVS index, r=1..........R (Regional Vaccine Store) |
| DVS index, d=1..........D (District Vaccine Store) |
| Clinic index, i=1..........I |
| Time index in a month, t=1..........T |

**Parameters: -**

|  |  |
| --- | --- |
|  |  |
| ***Inventory holding cost: -*** |  |
|  |  |
| SVS s holding cost at time t |  |
|  |  |
| RVS r holding cost at time t |  |
|  |  |
| DVS d holding cost at time t |  |
|  |  |
| Clinic i holding cost at time t |  |
|  |  |
| ***Transportation cost: -*** |  |
|  |  |
| Transportation cost from Mfr m to SVS s |  |
|  |  |
| Transportation cost from SVS s to RVS r |  |
|  |  |
| Transportation cost from RVS r to DVS d |  |
|  |  |
| Transportation cost from DVS d to Clinic i |  |
|  |  |
| ***Capacity: -*** |  |
|  |  |
| The capacity of SVS s at time t |  |
|  |  |
| The capacity of RVS r at time t |  |
|  |  |
| The capacity of DVS d at time t |  |
|  |  |
| The capacity of Clinic i at time t |  |
|  |  |
| ***Ordering cost: -*** |  |
|  |  |
| Cost of ordering vaccine by SVS s from Mfr m at time t |  |
|  |  |
| Cost of ordering vaccine by RVS r from SVS s at time t |  |
|  |  |
| Cost of ordering vaccine by DVS d from RVS r at time t |  |
|  |  |
| Cost of ordering vaccine by Clinic i from DVS d at time t |  |
|  |  |
| ***Miscellaneous: -*** |  |
| |  |  | | --- | --- | | Demand for vaccine units (doses) by sub-group j in the clinic I at time t |  | |  |
|  |  |
| Shortage cost for the unvaccinated customer in subgroup j at time t |  |
|  |  |
| Cost of clinical services for a single customer in subgroup j |  |
|  |  |
| Average time required to administrate vaccine |  |
|  |  |
| Medical personnel available in hrs in clinic i at time t |  |
|  |  |
| The cost incurred by manufacturer m for producing a vaccine unit at time t |  |
|  |  |
| The production capacity of manufacturer m at time t |  |
|  |  |
| Amount of vaccine required by SVS s at time t |  |

**Decision Variables: -**

|  |  |
| --- | --- |
| ***Inventory variables: -*** |  |
|  |  |
| Inventory in SVS s at the end of time t |  |
|  |  |
| Inventory in RVS r at the end of time t |  |
|  |  |
| Inventory in DVS d at the end of time t |  |
|  |  |
| Inventory in Clinic i at the end of time t |  |
|  |  |
| ***Quantity variables: -*** |  |
| Delivery quantity of vaccine unit from Mfr m to SVS s at time t |  |
|  |  |
| Delivery quantity of vaccine unit from SVS s to RVS r at time t |  |
|  |  |
| Delivery quantity of vaccine unit from RVS r to DVS d at time t |  |
|  |  |
| Delivery quantity of vaccine unit from DVS d to Clinic i at time t |  |
| **Shortage** in subgroup j in clinic i at time t |  |
| **Consumption** by subgroup j in clinic i at time t |  |

**Objective function: -**

Min =

Transportation cost \* vaccine units delivered from one cold chain points to other

Holding cost \* Inventory at cold chain points

Shortage cost \* Shortage of vaccine units at clinic

**Constraints: -**

***Inventory balance constraints: -***

***Consumption bounded by demand: -***

***Consumption balance: -***

(6)

***Total demand constraints: -***

***Inventory capacity constraints: -***

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***Production capacity constraints at manufacturer end: -***