1. **Problem Description**

This section describes the supply chain distribution network and its structure, assumptions, and related decisions. A multi-stage supply chain network is considered, consisting of supplier , airport , airport , hospitals in the red zone , orange zone , and green zone (demand node). The ventilators are transported from supplier nodes to the demand nodes through airport and airport .

This study focuses on Maharashtra, India, due to its significant impact during the COVID-19 pandemic. As the number of COVID-19 cases rapidly increases, numerous areas in Maharashtra have been transformed into containment zones. The severity of the virus has resulted in a considerable number of patients suffering from severe respiratory issues and experiencing an increase in mortality rates. A vital role is played by ventilators in saving the lives of critically ill patients with respiratory issues. The availability of ventilators in hospitals is crucial for effectively managing the critical patients those suffer from severe respiratory issues. However, the situation was hindered by an insufficient quantity of ventilators, leading to a shortage that delayed medical support and contributed to increased mortality rates.

To meet the emerging demand for ventilators in the red zone (severely affected regions), orange zone, green zone. It is essential to ensure fast delivery of ventilators across the COVID hospitals in the respective zones. While several studies have focused on designing supply chain networks to meet the requirement during natural disaster or pandemic situation and optimizing their performance, incorporating changes in network structure to reduce costs and maximize profit (Mehrotra et al., 2020; Simchi-Levi et al., 2019; Fattahi et al., 2017; Hammami et al., 2013; Hasani et al., 2015). However, no research has been reported on designing ventilator supply chain distribution networks, specifically to minimize delivery time using multimode transportation under pandemic demand conditions.

In this study, we propose the design of an VSCDN, aiming to minimize delivery time using multimode transportation. We operate under the assumption that it is not necessary for every network facility to utilize the full load capacity of a vehicle in order to ensure the timely delivery of ventilators. The VSCDN considered in this study includes multiple suppliers () located in different cities in China. The airport facilities are located near supplier locations and hospital regions. We consider the transportation links between suppliers () and airport (), airport () and airport (), and airport () and hospitals in the red zone (), hospitals in the orange zone (), hospitals in the green zone (), which is located at the district headquarters in Maharashtra, India. Also, the ventilators can be transferred only assigned facility nodes.

The objective of this study is to reduce the delivery time of ventilators distribution, taking into account loading, travel, and unloading time. The model aims to avoid holding a single ventilator at any stage of the VSCDN. The main decision in the model is to assign the airport (j) to the supplier (i), airport (k) to airport (j), and hospitals in the red, orange, and green zones to the airport (k). After assign the facility to respective suppliers and airports. Accordingly, establish the transportation link between each assigned facility. The model also determines the number of large capacity air cargo and truck types used for ventilators transportation and the quantities transported between different stages of the distribution network. Figure-1 provides an illustration of the proposed VSCDN.

1. **Model Formulation**

We have developed an MINLP model to minimize the delivery time of the ventilator and designed the structure of the supply chain distribution network by changing the different model parameters. The assumption considered in the proposed mathematical model is discussed below.

**Assumptions:**

1. Heterogeneous capacity large capacity trucks type and medium capacity trucks are available at the suppliers and airports , as the quantity of ventilators transported to the airport and demand points varies.
2. Heterogeneous capacity large capacity air cargo type are available at the airports , as the quantity of ventilators transported to the airport varies.
3. The weight of the ventilators is lower than the large capacity truck type , medium capacity truck type , and large capacity air cargo type .
4. Each vehicle can transport multiple ventilators, but its weight/volume capacity should never be exceeded.
5. Loading and unloading of all vehicles occur in parallel at all stages of the supply chain network.
6. No storage facilities are considered within the distribution network.
7. Red Zone is twice the priority of the orange zone and orange zone is twice the priority of the green zone.
8. Initially no ventilator is available at the airport (j) and airport (k)



Fig.1: Ventilator Supply Chain Distribution Network

|  |  |
| --- | --- |
| **Sets:** | |
| *i* Set of suppliers | |
| *j* Set of airports | |
| *k* Set of airports | |
| *n*  Set of hospitals in red zone | |
| *x* Set of large capacity air cargo  *z* Set of trucks | |
| **Parameters:** | |
| Number of ventilator available at the supplier | |
| Demand of ventilator at the hospitals in the red zone | |
| Distance between supplier and airports | |
| Distance between the airport and airport | |
| Distance between the airport and hospitals in the red zone | |
| Average speed of large capacity air cargo type | |
| Average speed of large capacity truck type | |
| Average speed of medium capacity truck type | |
| Loading time of large capacity truck type at the supplier | |
| Loading time of large capacity air cargo type at the airport | |
| Loading time of medium capacity truck type at the airport | |
| Unloading time of large capacity truck type at the airport | |
| Unloading time of large capacity air cargo type at the airport | |
| Unloading time of medium capacity truck type at hospitals in the red zone | |
| Loading capacity of large capacity truck type | |
| Loading capacity of large capacity air cargo type (x) | |
| Loading capacity of medium capacity truck type (y) | |
| Number of truck type (z) available at supplier (i)  Number of aircraft type (x) available at airport (j)  Number of truck type (z) available at airport (k)   |  | | --- | | **Decision Variables:** | | ***Integer Variables:*** | | Number of ventilators transported through road from the supplier to airport  where | | Number of ventilators transported through air from the airport to airport  where | | Number of ventilators transported through road from airport to hospitals in the red | | zone | | Number of large capacity truck type used from supplier to airport | | Number of large capacity air cargo type used from airport to airport | | Number of medium capacity truck type used from airport to hospitals in  the red zone | | Delivery time from supplier to airport | | Delivery time from airport to airport | | Delivery time from airport to hospitals in the red zone | |  | |  | | ***Binary Variables:*** | |  | |  | |  | |  | | |
|  | |

|  |
| --- |
|  |
|  |
|  |
| **Objective Function**  The objective function minimizes the delivery time of ventilators distribution from supplier airport , from airport to airport , from airport to hospitals in the red zone (n1). The ventilators' delivery time components include the loading time, travel time, and unloading time of vehicles.  Minimize the overall delivery lead time of ventilator distribution = [total delivery time from supplier to airport ] + [total delivery time from airport to airport ] + [total delivery time from airport to hospitals in the red zone ]   |  | | --- | | Minimize total delivery time |   **Constraints:**   |  | | --- | |  | |  | |  |   Constraints (2)-(4) specify the transportation of the ventilator from the supplier (i) to the airport (j) if the airport (j) is allocated to the supplier (i), from the airport (j) to the airport (k) if the airport (k) is allocated to the airport (j), from the airport (k) to the hospitals in the red zone (n1) if the hospital in the red zone (n1) is allocated to the airport (k), from the airport (k) to the hospitals in the orange zone (n2) if the hospital in the orange zone (n2) is allocated to the airport (k), and from the airport (k) to the hospitals in the green zone (n3) if the hospital in the green zone (n3) is allocated to the airport (k).       |  | | --- | |  |   Constraints (5)-(7) guarantee that each airport (j) is assigned to a maximum of one supplier (i), each airport (k) is assigned to an airport (j), each hospital in the red zone (n1) is assigned to a maximum of one airport (k), each hospital in the orange zone (n2) is assigned to a maximum of one airport (k), and each hospital in the green zone (n3) is assigned to a maximum of one airport (k).   |  | | --- | |  | |  | |  |   Constraint (12) shows that number of ventilators transferred from the airport to the hospitals in the red zone using medium capacity truck type (y) must be greater than and equal to the demand of the ventilators at hospitals in the red zone. Constraint (13) shows that number of ventilators transferred from the airport to the hospitals in the red zone using medium capacity truck type (y) must be greater than and equal to the demand of the ventilators at hospitals in the orange zone . Constraint (14) shows that number of ventilators transferred from the airport to the hospitals in the green zone using medium capacity truck type (y) must be greater than and equal to the demand of the ventilators at hospitals in the green zone .   |  | | --- | |  | |  | |  |   Constraint (12) shows that the ventilator quantities transferred from the supplier to supplier side airport are less than or equal to the number of ventilators transported when each large capacity truck type runs within the capacity. Constraint (13) shows that the ventilator quantities transported from the supplier side airport to demand side airport are less than or equal to the number of ventilators transported when each large capacity air cargo type runs within the capacity. Constraint (14) shows that ventilators quantities transported from supplier side airport to the hospitals in the red zone are less than or equal to the number of ventilators transported when each medium capacity truck type runs within the capacity. Constraint (15) shows that ventilators quantities transported from supplier side airport to the hospitals in the orange zone are less than or equal to the number of ventilators transported when each medium capacity truck type runs within the capacity. Constraint (16) shows that ventilators quantities transported from supplier side airport to the hospitals in the green zone are less than or equal to the number of ventilators transported when each medium capacity truck type runs within the capacity.  **Vehicle Constraint**   |  | | --- | |  | |  | |  |   Constraint (11) limits the number of trucks type (z) used between supplier (i) to airport (j), must be less than equal to the maximum available number of trucks type (z) at the supplier (i). Constraint (12) limits the number of aircraft type (x) used between airport (j) to airport (k), must be less than equal to the maximum available number of aircraft type (x) at the airport (j). Constraint (13) limits the number of trucks type (z) used between airport (k) to hospital demand district hospital (n), must be less than equal to the maximum available number of trucks type (z) at the airport (k).   |  | | --- | |  | |  | |  |   Constraints (14)–(16) determine the delivery time from the supplier (i) to the airport (j), from the airport (j) to the airport (k), from the airport (k) to the hospitals in the red zone (n1), from the airport (k) to the hospitals in the orange zone (n2), from the airport (k) to the hospitals in the green zone (n3).  **Truck preference constraints:**   |  | | --- | |  | |  | |  | |  |   Constraints (17)-(20) defines the large size trucks preference constraints. In this paper, we have considered three different capacitated large size truck for transportation of ventilator between first stage of the network (supplier i to airport j). These constraints ensure the high-capacity trucks should fill first in order to minimize the time for delivery of ventilator.   |  | | --- | |  | |  | |  | |  |   Constraints (21)-(24) defines the medium size trucks preference constraints. In this paper, we have considered two different capacitated medium size truck for transportation of ventilator between last stage of the network (airport to district hospital ). These constraints ensure the high-capacity trucks should fill first in order to minimize the time for delivery of ventilator.  **Aircrafts preference constraints:**   |  | | --- | |  | |  | |  | |  |  |  | | --- | |  | |  | |  |   Constraints (29)-(34) depict binary variables respectively employed in the model.   |  | | --- | | ***Non- Negativity Constraints:*** | |  | | (40) | |  | |  | |  | |  | |  | |  |   Non-negativity constraints are indicated by constraints (38) - (46). |

source: [www.covid19india.org](http://www.covid19india.org)

**Table 1:** Input parameters data ranges

**Input Parameters Assume the range of input parameters values**

Speed of aircraft x (km/mins) 10.83-15.22

Speed of medium size truck y (km/mins) 0.83-1.17

Speed of large size truck z (km/mins) 0.67-0.92

Loading time of large size truck type z at supplier i (mins) 120-150

Loading time of aircraft type x at airport j (mins) 180-240

Loading time of medium size truck type y at airport k (mins) 30-60

Unloading time of large size truck type z at airport j (mins) 60-90

Unloading time of aircraft type x at airport k (mins) 120-180

Unloading time of medium size truck type y at hospital region n (mins) 15-30

Loading capacity of large-size truck z (Kg) 14515

Loading capacity of aircraft x1 (Kg) 21000

Loading capacity of medium size truck type y1 (Kg) 4535

Distance from supplier i to airport j (km) 14.8-2217.5

Distance from airport j to airport k (km) 3972-4872

Distance from airport k to hospital region n (km) 6.8-1001

Weight of each ventilator (Kg) 116

**Results of the case study**

The results of the case study are investigated in this sub-section. Accordingly, Table 1 shows the allocation of hospitals in the red zone (n1) to airport (k). Table 2 (a) and Table 2(b) present the allocation of hospitals in the orange zone (n2) to airport (k). Similarly, Table 3 shows the allocation of hospitals in the green zone (n3) to airport (k). Due to importance of the ventilator delivery time

**Sensitivity analysis**

Table 1 Allocation of Airport to Supplier

|  |  |  |
| --- | --- | --- |
| I/J |  |  |
|  | 1 | 1 |

Table 2 Allocation of Airport to Airport *(j)*

|  |  |  |  |
| --- | --- | --- | --- |
| J/K |  |  |  |
|  | 0 | 1 | 0 |
|  | 1 | 0 | 1 |

J1 94864

J2 111357

Table 3 Allocation of hospitals in the red zone (n1) to Airport (k)

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| K/N1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| K1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| K2 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 |
| K3 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 4(a) Allocation of hospitals in the orange zone (n2) to Airport (k)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| K/N2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|  | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
|  | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 |
|  | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 |

Table 4(b) Allocation of hospitals in the orange zone (n2) to Airport (k)

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| K/N2 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|  | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
|  | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
|  | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 |

Table 5 Allocation of hospitals in the green zone (n3) to Airport (k)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| K/N3 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| K1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| K2 | 1 | 0 | 0 | 0 | 1 | 1 | 0 |
| K3 | 0 | 0 | 1 | 1 | 0 | 0 | 1 |

Table 5 Results for the case study solution

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Hospitals in All Zone | Hospitals in the Red Zone (n1) | Hospitals in the Orange Zone (n2) | Hospitals in the Green Zone (n3) |
| Delivery Time (%) | 100 | 55 | 30 | 15 |