Oxygen Planner for States in India

STCS TIFR Oxygen Planner Team*

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1 Introduction

In this report we briefly outline the methodology for projecting oxygen requirement as well as scheduling oxygen supply using our oxygen planner tool. The methodology and the tool are work in progress and this document will be accordingly updated to sync with the tool. The tool is meant to help Indian states better plan the scheduling of oxygen supply to different state districts.

1.1 Projecting Oxygen Requirement

Methodology for projectioning oxygen requirement for a district or a state is based on the number of reported cases in that region. The source for the daily case data is [2] . We use the *Guidelines for rational use of oxygen for management of COVID-19* provided Ministry of Health and Family welfare [4] to arrive at patient categories, the time at which oxygen is started and duration for which it is required and the amount of oxygen required per unit time by patients in each category. To arrive at the start time of administering oxygen, we also use numbers suggested by our modelling effort [1]. The above data allows us to arrive at short-term projections for oxygen requirement.

Below we spell out the variables considered and the default value of associated parameters. The default values are reported in brackets. The specific parameter values may vary from region to region. Sliders have been provided to tune these to better fit the data of the region (district/state) considered.

1. **Reported cases in different patient categories:** Severity of the disease vary in different COVID-19 patients and not all cases require oxygen support. The reported cases are divided into following categories: Patients with

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- mild disease. These do not require any hospitalization and oxygen. (80% of reported cases).
- moderate disease requiring minimal oxygen. These are hospitalized but require minimal or no oxygen support. (8.5%).
- moderate disease having low oxygen requirement. (8.5%).
- serious disease requiring ICU beds with invasive ventilation. (0.6%).
- serious disease requiring ICU beds with non - invasive ventilation / high flow nasal cannula (HFNC). (1.2%).
- serious disease requiring ICU beds with non re-breathing masks (NRBM). (1.2%).

2. **Start timings and duration of administered oxygen:**

- Patients with mild disease do not require hospitalization.
- Patients with moderate disease are assumed to follow the following timings after case detection:
  - Period between case detection and start of hospitalisation. (3 days).
  - Period of hospitalisation. (7 days).
- Patients with severe disease are first admitted in non-ICU wards. The period between detection of case and start of non-ICU hospitalisation is same as that for patients with moderate disease (3 days). After some time, these patients are transferred to ICU wards and observe the following time periods:
  - Period between case detection and start of intensive care . (11 days).
  - Period of intensive care . (18 days).

3. **Oxygen requirement of different patient categories:**

- Patients with moderate disease requiring minimal oxygen (0 litres/min) and those having low oxygen requirement (5 litres/min).
- Patients with serious disease have low oxygen requirements during non-ICU hospitalization period (5 litres/min). After that during intensive care, severe patients have following oxygen requirements:
  - ICU beds with invasive ventilation. (10 litres/min)
  - ICU beds with non - invasive ventilation / high flow nasal cannula (HFNC). (30 litres/min)
  - ICU beds with non re-breathing masks (NRBM). (12 litres/min)

1.1.1 Calculating the required oxygen

Let C_i denotes the number of cases reported on day i. Then projections of oxygen requirement R_d on Day d is computed as follows (using default parameter values):

$$R_d = K \cdot \Bigg(\sum_{i=d-9}^{d-3} C_i * 0.085 * 5 + \sum_{i=d-28}^{d-11} C_i * (0.006 * 10 + 0.012 * 30 + 0.012 * 12) + \sum_{i=d-10}^{d-3} C_i * (0.006 * 5 + 0.012 * 5 + 0.012 * 5) \Bigg)$$

where, $K = 24 * 60/700,000$ since each metric ton corresponds to 700,000 litres of oxygen.

Currently in our tool we project oxygen requirements for seven days in future. To this end, we need to project reported cases for the next four days (for calculating requirements for moderate and severe cases). We assume that the cases for each of the next four days equal the average of daily cases for the last seven days. This is simple and reasonable as the projected requirements have little sensitivity to these projections as bulk of the contribution to oxygen requirement comes from intensive care patients with severe disease. For these cases, the observed data suffices in arriving at projections.

1.2 Scheduling the Oxygen Supply

We now discuss our formulation of the supply scheduling problem as a linear program (LP) where the demand projected above is taken as the input.

1.2.1 Notation for constants in the LP

Let

- n denote the total number of supply nodes and S_i denote the name of supply node i. These names are entered by the user in the input data sheet.
- m denote the total number of districts in a state and D_j denote the name of district j. These names can be downloaded from our demand projection tool.
- t_{ij} denote the travel time (in days) between supply node S_i and district D_j for each i and j. These need to be entered by the user in the input data sheet.
- c_i, for each i, denote the maximum amount of oxygen that supply node S_i can supply in a day. This again is input by the user.

- q denote the number of days for which supply schedule is to be computed. Currently, we have taken this to be seven or one week.
- d_{jk} denote the demand projection for district D_j on day k. This can be downloaded from our demand projection tool.
- i_j^0 denote the initial inventory available at district D_j on day 0 for each j. User inputs this.
- q_j denote the maximum quantity of oxygen district D_j can store at any j. User inputs this.
- r_{ijk} denotes the quantity of oxygen in transit that is supplied from supply node i and will reach district D_j on day k for each i, j and k.

1.2.2 Variables in the LP

Let

- i_{jk} denote the inventory for district j at end of day k for each j and k.
- x_{ijk} denote the quantity of oxygen dispatched from supply node i to district j on day k for each i, j and k. Note that this supply will reach the district j after time t_{ij}, i.e. on day $k + t_{ij}$.
- s_{jk} denote the deficit (or external supply) of oxygen in district j on day k for each j and k.

1.2.3 Linear Program

The LP for optimizing the oxygen supplies to different districts is as follows:

1.3 Constraints

- The total amount of oxygen supplied by a supply node in a day is limited to its supply capacity . Therefore for all supply nodes S_i following holds on each day k

$$\sum_{j=1}^{m} x_{ijk} \leq c_i \quad \text{for all } i \leq n, k \leq q.$$

- Inventory in a district should be less than the storage capacity of the district. Therefore,

$$i_{jk} \leq q_j \quad \text{for all } j \leq m, k \leq q.$$

- For each district the net amount of supply (i.e. supply - demand) in a day should be equal to the net change in the inventory of that day. In addition we introduce a slack variable (external supply or deficit) for each district on each day to cover any shortage on that day, although to prevent this, we assign a very high cost to this variable in the objective. So high optimal cost denotes that existing supply, inventory and transit amount cannot meet the specified demand.

For each district D_j on Day 1,

$$\Big(\sum_{i=1}^{n}\sum_{k=1}^{q}\mathbb{1}(k+t_{ij}=1)\cdot x_{ijk}\Big)+\Big(\sum_{i=1}^{n}r_{ij1}\Big)+i_j^0+s_{j1}=i_{j1}+d_{j1},$$

where, for any w, the indicator notation $\mathbb{1}(k+t_{ij}=w)=1$ if $k+t_{ij}=w$ and it equals zero otherwise.

For each district D_j on Day r other than Day 1,

$$\Big(\sum_{i=1}^{n}\sum_{k=1}^{q}\mathbb{1}(k+t_{ij}=r)\cdot x_{ijk}\Big)+\Big(\sum_{i=1}^{s}r_{ijk}\Big)+i_{j,r-1}+s_{jr}=i_{jr}+d_{jr}.$$

Objective function of the LP is set to

$$\textbf{Minimize}\ \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{q}t_{ij}\cdot x_{ijk}+\sum_{j=1}^{m}\sum_{k=1}^{q}100{,}000\cdot s_{jk}.$$

We solve this LP using the CLP Linear Programming Solver ported to the WebAssembly [3]

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[2] https://api.covid19india.org/

[3] https://github.com/dpar39/clp-wasm

[4] https://covid19.karnataka.gov.in/storage/pdf-files/cir-hws/Circular-Guidelines%20for%20Rational%20use%20of%20Oxygen%20for%20Management%20of%20COVID-19%20and%20Safe%20Storage,%20Transportation%20and%20Handling%20of%20Liquid%20Oxygen%20for%20Medical%20Use.pdf