PLANNING MEDICAL OXYGEN SUPPLY DISTRIBUTION TO TREAT HOSPITALIZED COVID-19 INFECTED PATIENTS

Thiago Berton Ferreira
thiago.ferreira96@edu.pucrs.br

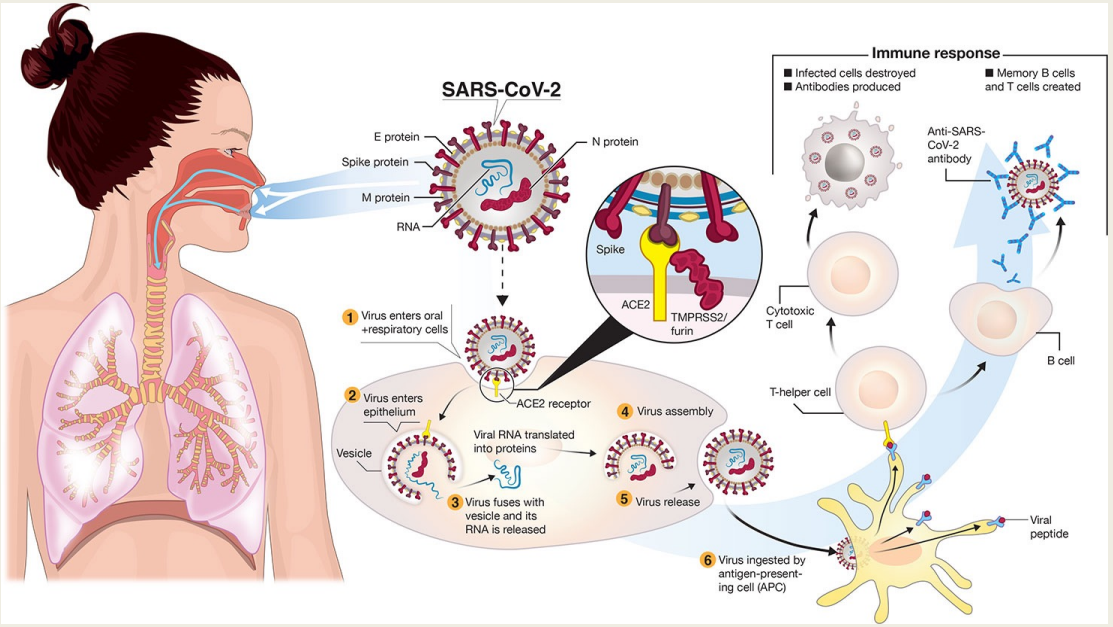
Graduate Program in Computer Science – School of Technology Pontifical Catholic University of Rio Grande do Sul (PURCRS)

Agenda

- Introduction
- Formalization
  - Domain Description
  - Problem Description
- Experiments and Results
- Conclusion and Future Work

Introduction

- The novel coronavirus disease (also known as COVID-19) is a highly infectious disease.
- It is caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2).
- Transmitted through droplets generated when an infected person coughs, sneezes, or exhales.
- Symptoms usually are fever, cough, headache, fatigue and breathing difficulties.



- The most common cases are infection on the lungs causing pneumonia.
- The lungs become filled with fluid and inflamed, leading to breathing difficulties.

Introduction

- Modeling approaches have been developed to fight, in different ways, the COVID-19 pandemic.
- For example, a framework were developed to assess the effectiveness of intervention strategies such as social distancing and mask use (IHME, 2020).
- Also, Oliveira et al. (2021) estimate the number of beds required to attend the population in Bahia, Brazil based on the data from the first wave of COVID-19 in Brazil.
- However, not a single model was developed for disaster response such as shortages of oxygen supply that was faced by hospitals cross several nations.

Objective: Developer a planner to estimate the minimal oxygen required in hospitals and the transportation logistic required to help avoid the collapse of health systems due to shortage of oxygen supply.

Formalization

- Language: PDDL+
- Dev. Environment/Planner: ENHSP
- Search heuristic: A*
- Heuristic: AIBR (Additive Interval-based relaxation)

Domain Description

- **Predicates (3)** and **functions (10)**

```
(:predicates
  (connected_road ?x ?y - location)
  (connected_airway ?x ?y - location)
  (oxygen_location ?fact - factory ?x - location)
)
```

```
(:functions
  (num_patients ?h - hospital)
  (oxygen_per_person)
  (carrying ?t - transport)
  (hospital_oxygen ?h - hospital)
  (payload)
  (required_oxygen ?h - hospital)
  (daily_oxygen_volume_produced_per_machine ?f - factory)
  (num_machines ?f - factory)
  (fact_oxygen_production_capacity ?f - factory)
  (distance ?x ?y - location)
)
```

Domain Description

- Actions (7)

```
(:action oxygen_production_capacity
    :parameters (?f - factory)
    :precondition (and
      (> (daily_oxygen_volume_produced_per_machine ?f) 0)
      (> (num_machines ?f) 0)
    )
    :effect (and
      (assign (fact_oxygen_production_capacity ?f) (* (daily_oxygen_volume_produced_per_machine ?f) (num_machines ?f)))
    )
)
(:action calculate_oxygen_required
    :parameters (?h - hospital)
    :precondition (and
      (> (num_patients ?h) 0)
      (> (oxygen_per_person) 0)
    )
    :effect (and
      (assign (required_oxygen ?h) (* (num_patients ?h) (oxygen_per_person)))
    )
)
(:action load_oxygen_transportation
  :parameters (?f - factory ?h - hospital)
  :precondition (and
    (>= (fact_oxygen_production_capacity ?f) (required_oxygen ?h))
  )
  :effect (and
    (assign (payload) (required_oxygen ?h))
    (oxygen_location ?f ?f)
  )
)
```

Domain Description

- Actions (7)

```
(:action transport_truck_local
 :parameters (?x ?y - location ?h - hospital ?f - factory ?t - local_truck)
 :precondition (and
    (< (hospital_oxygen ?h) (required_oxygen ?h))
    (connected_road ?x ?y)
    (<= (distance ?x ?y) 100)
    (oxygen_location ?f ?x)
    (> (payload) 0)
 )
 :effect (and
    (assign (carrying ?t) (payload))
    (not(oxygen_location ?f ?x))
    (oxygen_location ?f ?y)
 )
)

 (:action transport_plane
  :parameters (?x ?y - location ?h - hospital ?f - factory ?t - airplane)
  :precondition (and
     (< (hospital_oxygen ?h) (required_oxygen ?h))
     (connected_airway ?x ?y)
     (> (distance ?x ?y) 500)
     (oxygen_location ?f ?x)
     (> (payload) 0)
   )
  :effect (and
     (assign (carrying ?t) (payload))
     (not(oxygen_location ?f ?x))
     (oxygen_location ?f ?y)
   )
  )
```

```
(:action transport_truck_intercity
 :parameters (?x ?y - location ?h - hospital ?f - factory ?t - intercity_truck)
 :precondition (and
    (< (hospital_oxygen ?h) (required_oxygen ?h))
    (connected_road ?x ?y)
    (> (distance ?x ?y) 100)
    (< (distance ?x ?y) 500)
    (oxygen_location ?f ?x)
    (> (payload) 0)
 )
 :effect (and
    (assign (carrying ?t) (payload))
    (not(oxygen_location ?f ?x))
    (oxygen_location ?f ?y)
 )
)
```

```
(:action deliver_oxygen
  :parameters (?f - factory ?h - hospital ?t - road_transport)
  :precondition (and
    (< (hospital_oxygen ?h) (required_oxygen ?h))
    (> (carrying ?t) 0)
    (oxygen_location ?f ?h)
  )
  :effect (and
    (assign (hospital_oxygen ?h) (carrying ?t))
    (assign (carrying ?t) 0)
  )
)
```

Problem Description

- (:init)

Connections

Connections between entities (Airways and roads)
Distance between entities (km)

```
(connected_road factory_1 airport_X)
(= (distance factory_1 airport_X) 90)
(connected_airway airport_X airport_Y)
(= (distance airport_X airport_Y) 1450)
(connected road airport Y hospital 1)
(= (distance airport_Y hospital_1) 450)
```

Hospital

Initial oxygen level on hospital
Number of hospitalized patients
Oxygen consumed per patient

```
(= (hospital_oxygen hospital_1) 0)
(= (num_patients hospital_1) 220)
(= (oxygen_per_person) 300)
```

Factory

Daily production per machine
Number of machines

```
(= (daily_oxygen_volume_produced_per_machine factory_1) 1000)
(= (num_machines factory_1) 30)
```

Problem Description

- (:goal)

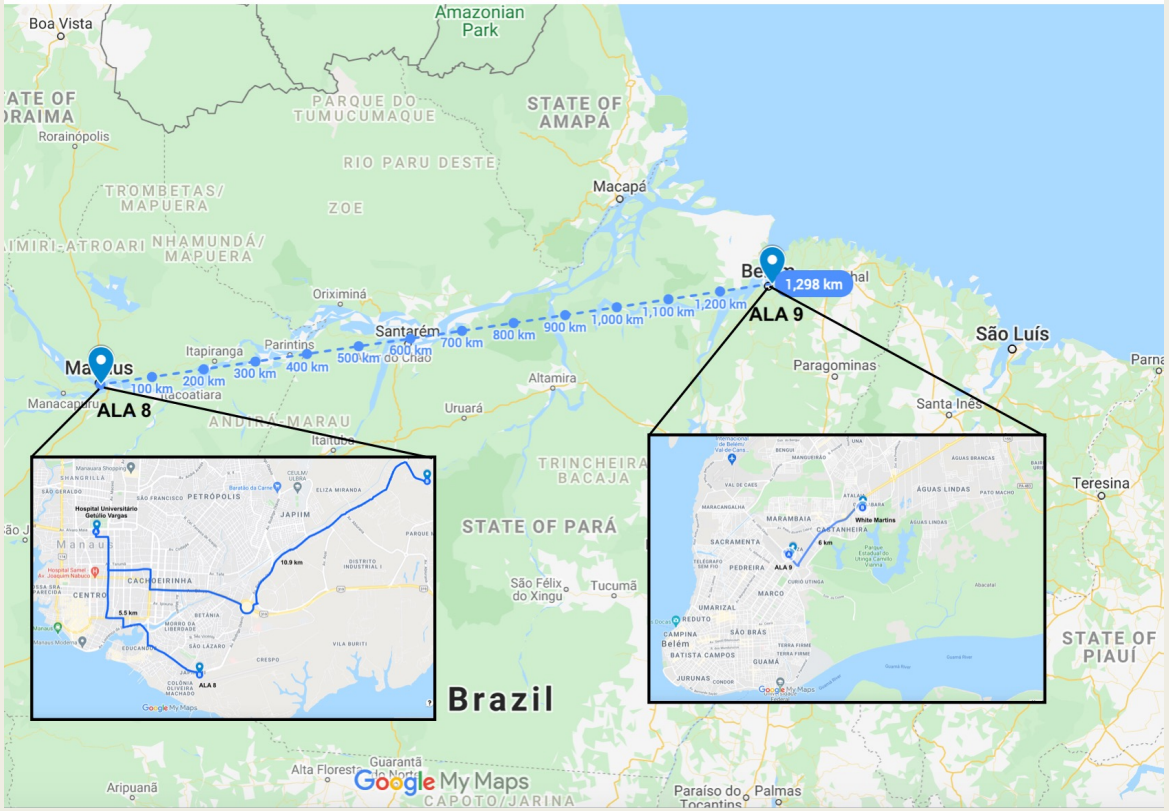
```
(:goal
    (= (hospital_oxygen hospital_1) (required_oxygen hospital_1))
)
```

Two experiments were conducted to evaluate the developed planner.

Experiments and Results

Experiment 1

- The first problem description was created to represent the situation of a single hospital in Manaus, Amazonas - Brazil in January 2021 that suffered with shortage of oxygen tanks.
- The problem description was defined with:
  - **One hospital** (Hospital Universitário Getulio Vargas, Manaus);
  - **Two airports** (Brazilian air force base ALA8, Manaus and ALA9, Belém);
  - Two oxygen factories (White Martins factories in Manaus and Belém);
  - Roads and airways connections;



Experiments and Results

```
Problem Solved
0.0: (oxygen_production_capacity White_Martins_Belem)
1.0: (calculate_oxygen_required Hospital_Universitario_Getulio_Vargas)
2.0: (load_oxygen_transportation White_Martins_Belem Hospital_Universitario_Getulio_Vargas)
3.0: (transport_truck_local White_Martins_Belem Air_Force_base_ALA_9-Belem Hospital_Universitario_Getulio_Vargas White_Martins_Belem truck_local)
4.0: (transport_plane Air_Force_base_ALA_9-Belem Air_Force_base_ALA_8-Manaus Hospital_Universitario_Getulio_Vargas White_Martins_Belem C-130_Hercules)
5.0: (transport_truck_local Air_Force_base_ALA_8-Manaus Hospital_Universitario_Getulio_Vargas Hospital_Universitario_Getulio_Vargas White_Martins_Belem truck_local)
6.0: (deliver_oxygen White_Martins_Belem Hospital_Universitario_Getulio_Vargas truck_local)
```

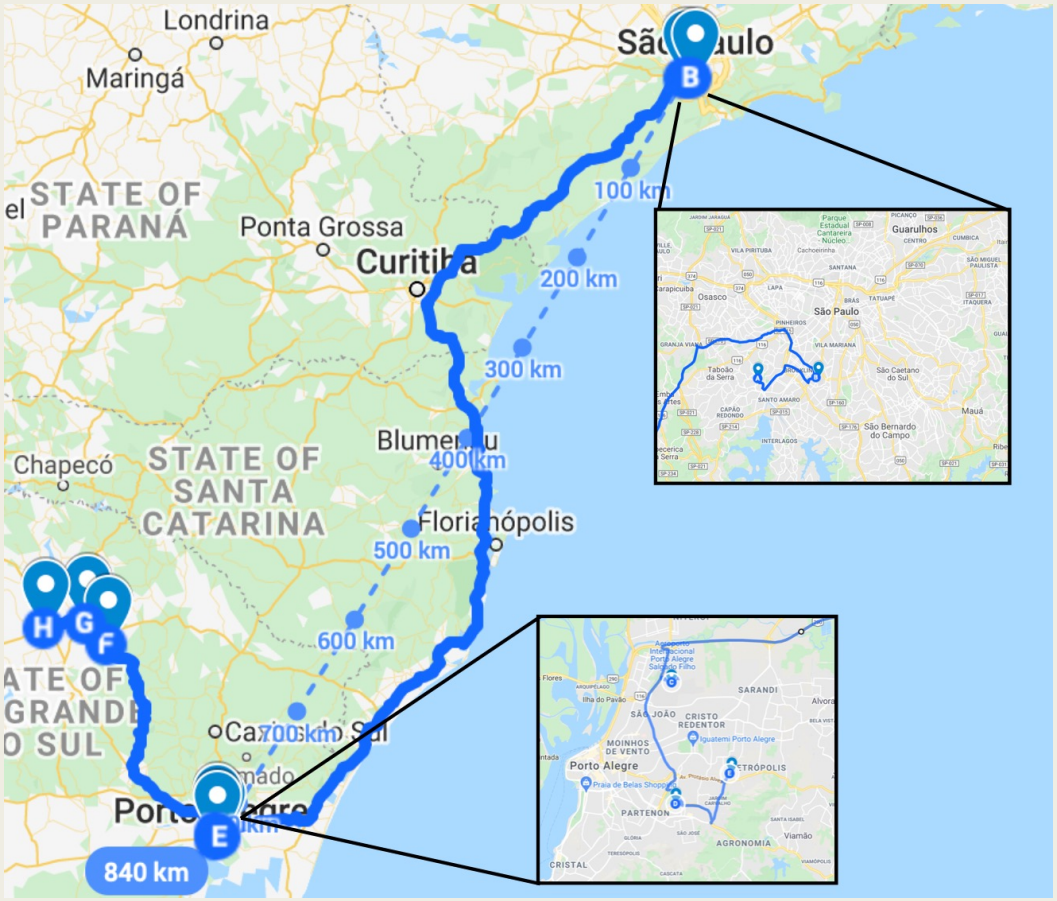
TIME:
0.02 seconds

Problem Solved
0.0: (oxygen_production_capacity White_Martins_Belem)
1.0: (calculate_oxygen_required Hospital_Universitario_Getulio_Vargas)
2.0: (load_oxygen_transportation White_Martins_Belem Hospital_Universitario_Getulio_Vargas)
3.0: (transport_truck_local White_Martins_Belem Air_Force_base_ALA_9-Belem Hospital_Universitario_Getulio_Vargas White_Martins_Belem truck_local)
4.0: (transport_plane Air_Force_base_ALA_9-Belem Air_Force_base_ALA_8-Manaus Hospital_Universitario_Getulio_Vargas White_Martins_Belem C-130_Hercules)
5.0: (transport_truck_local Air_Force_base_ALA_8-Manaus Hospital_Universitario_Getulio_Vargas Hospital_Universitario_Getulio_Vargas White_Martins_Belem truck_local)
6.0: (deliver_oxygen White_Martins_Belem Hospital_Universitario_Getulio_Vargas truck_local)

Experiments and Results

Experiment 2

- A hypothetical scenario was developed to analyze a broader and more complex environment.
- This problem description consists of:
  - One small-size factory in Porto Alegre, RS – Brazil;
  - One large-scale factory in São Paulo, SP – Brazil;
  - Hospitals in Rio Grande do Sul including Passo Fundo, Carazinho, and Marau;
  - Two airports (Porto Alegre and São Paulo) connected through airways and the roads connecting these entities.
- Hospitals in Passo Fundo, Carazinho, and Marau had a relatively small oxygen demand while the hospital in Porto Alegre had a significantly larger request.



Experiments and Results

TIME:
0.34 seconds

```
Problem Solved
0.0: (oxygen_production_capacity factory_Sao_Paulo)
1.0: (calculate_oxygen_required HSL_Porto_Alegre)
2.0: (load_oxygen_transportation factory_Sao_Paulo HSL_Porto_Alegre)
3.0: (transport_truck_local factory_Sao_Paulo CGH_Sao_Paulo HSL_Porto_Alegre factory_Sao_Paulo truck_local)
4.0: (transport_plane CGH_Sao_Paulo POA_Porto_Alegre HSL_Porto_Alegre factory_Sao_Paulo Boeing_747)
5.0: (transport_truck_local POA_Porto_Alegre HSL_Porto_Alegre HSL_Porto_Alegre factory_Sao_Paulo truck_local)
6.0: (deliver_oxygen factory_Sao_Paulo HSL_Porto_Alegre truck_local)
7.0: (calculate_oxygen_required HCC_Carazinho)
8.0: (oxygen_production_capacity factory_Porto_Alegre)
9.0: (load_oxygen_transportation factory_Porto_Alegre HCC_Carazinho)
10.0: (transport_truck_intercity factory_Porto_Alegre HCC_Carazinho HCC_Carazinho factory_Porto_Alegre truck_intercity)
11.0: (deliver_oxygen factory_Porto_Alegre HCC_Carazinho truck_intercity)
12.0: (calculate_oxygen_required HSVP_Passo_Fundo)
13.0: (load_oxygen_transportation factory_Porto_Alegre HSVP_Passo_Fundo)
14.0: (transport_truck_intercity factory_Porto_Alegre HSVP_Passo_Fundo HSVP_Passo_Fundo factory_Porto_Alegre truck_intercity)
15.0: (deliver_oxygen factory_Porto_Alegre HSVP_Passo_Fundo truck_intercity)
16.0: (calculate_oxygen_required HCR_Marau)
17.0: (load_oxygen_transportation factory_Porto_Alegre HCR_Marau)
18.0: (transport_truck_intercity factory_Porto_Alegre HCR_Marau HCR_Marau factory_Porto_Alegre truck_intercity)
19.0: (deliver_oxygen factory_Porto_Alegre HCR_Marau truck_intercity)
```


Hospital Porto Alegre
0.0: (oxygen_production_capacity factory_Sao_Paulo)
1.0: (calculate_oxygen_required HSL_Porto_Alegre)
2.0: (load_oxygen_transportation factory_Sao_Paulo HSL_Porto_Alegre)
3.0: (transport_truck_local factory_Sao_Paulo CGH_Sao_Paulo HSL_Porto_Alegre factory_Sao_Paulo truck_local)
4.0: (transport_plane CGH_Sao_Paulo POA_Porto_Alegre HSL_Porto_Alegre factory_Sao_Paulo Boeing_747)
5.0: (transport_truck_local POA_Porto_Alegre HSL_Porto_Alegre HSL_Porto_Alegre factory_Sao_Paulo truck_local)
6.0: (deliver_oxygen factory_Sao_Paulo HSL_Porto_Alegre truck_local)
Hospital Carazinho
7.0: (calculate_oxygen_required HCC_Carazinho)
8.0: (oxygen_production_capacity factory_Porto_Alegre)
9.0: (load_oxygen_transportation factory_Porto_Alegre HCC_Carazinho)
10.0: (transport_truck_intercity factory_Porto_Alegre HCC_Carazinho HCC_Carazinho factory_Porto_Alegre truck_intercity)
11.0: (deliver_oxygen factory_Porto_Alegre HCC_Carazinho truck_intercity)
Hospital Passo Fundo
12.0: (calculate_oxygen_required HSVP_Passo_Fundo)
13.0: (load_oxygen_transportation factory_Porto_Alegre HSVP_Passo_Fundo)
14.0: (transport_truck_intercity factory_Porto_Alegre HSVP_Passo_Fundo HSVP_Passo_Fundo factory_Porto_Alegre truck_intercity)
15.0: (deliver_oxygen factory_Porto_Alegre HSVP_Passo_Fundo truck_intercity)
Hospital Marau
16.0: (calculate_oxygen_required HCR_Marau)
17.0: (load_oxygen_transportation factory_Porto_Alegre HCR_Marau)
18.0: (transport_truck_intercity factory_Porto_Alegre HCR_Marau HCR_Marau factory_Porto_Alegre truck_intercity)
19.0: (deliver_oxygen factory_Porto_Alegre HCR_Marau truck_intercity)

Conclusion and Future Work

- This study is an initial step for estimating the demand for oxygen supply in hospitals and healthcare facilities to help avoid oxygen shortages.
- Ideally, this planner can be used to minimize the risks of health system collapse due to the shortages of oxygen for medical oxygen therapy.
- The scalability of the developed planner allows the definition of problems that can variate according to the area of study.
- Future work will incorporate into the source code the transportation capacity for each transportation method.
- Additionally, explore specific scenarios in which some transportation methods may not be available.

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Thank you!