Custom solution for hospital assignment problem during COVID-19

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Introduction

Studying the solution proposed in the paper *Challenges and solutions for the integrated recovery room planning and scheduling problem during COVID-19 pandemic*, published by Marouane Chaieb, Dhekra Ben Sassi, Jaber Jemai and Khaled Mellouli, we decided to implement a custom solution for this assignment problem. This solution broadly follows the original solution proposed by the paper, with some major differences in terms of problem and constraints definitions.

Defining the problem

In this subchapter, we will provide a detailed description of how we defined the problem and the constraints. While in the original paper they used 2 possible types of patients (critical and severe), which are correlated with 2 possible types of nurses (one type of nurse for each type of patient), we decided to define the problem for a generic nurse and a generic patient. After all, we can solve the original problem by splitting it into 2 branches: one with critical patients and the specialized nurses and one with the severe cases, treated by other nurses.

Because we can not use the data used for the paper because it is sensible and provided by the government, we decided to generate data to simulate a real life scenario. The variables that we used in the problem are:

- **num_days** - number of days for which data will be generated
- **num_nurses** - number of nurses
- **num_patients** - number of patients
- **num_shifts** - number of shifts (usually 3 shifts of 8 hours each)
- **max_treatment_duration** - maximum duration for a treatment (in chunks of 10 minutes)
- **max_working_time** - maximum working time for a nurse (usually 8 hours)

Data is generated randomly, both for patients and for nurses. An entry for a patient has the form (**day, patient, shift, treatment_duration**) while an entry for a nurse has the form (**day, nurse, shift**). The patients and nurses are splitted equally to shifts to make the problem balanced. Every day, a patient or a nurse can be assigned to different shifts.

The main constraints that should be respected are:

- A patient should be treated by at most one nurse in a day.
- A nurse can not work more than maximum working time per day(8 hours); this time is calculated as the sum of treatment durations per patient in a day.
- A patient with a scheduled treatment in a shift should be treated only by a nurse who is working in the same shift (patient_shift = nurse_shift).

The objective of the problem is to maximize the number of treated patients during the number of days defined.

Proposed solution and results

The solution is implemented in Python and it uses the OR Tools framework and Cp Solver.
We defined a dictionary called assignments of the form {(**day, nurse, patient**): **BoolVar**} where True value corresponds to the following predicate: "On day **day**, nurse **nurse** will treat patient **patient**". The constraints are defined using this dictionary.
In the following, we provide 5 scenarios with the specific results:

Scenario 1

- num_nurses = 50
- num_shifts = 3
- num_days = 10
- num_patients = 300
- max_treatment_duration = 12 # in 10 minutes chunks
- max_working_time = 8 * 60 # in minutes

Result

On day 0, number of treated patients: 300 / 300
On day 1, number of treated patients: 300 / 300
On day 2, number of treated patients: 300 / 300
On day 3, number of treated patients: 300 / 300
On day 4, number of treated patients: 300 / 300
On day 5, number of treated patients: 300 / 300
On day 6, number of treated patients: 300 / 300
On day 7, number of treated patients: 297 / 300
On day 8, number of treated patients: 300 / 300
On day 9, number of treated patients: 300 / 300

Scenario 2

- num_nurses = 7
- num_shifts = 3
- num_days = 5
- num_patients = 100
- max_treatment_duration = 10 # in 10 minutes chunks
- max_working_time = 8 * 60 # in minutes

Result

On day 0, number of treated patients: 76 / 100
On day 1, number of treated patients: 74 / 100
On day 2, number of treated patients: 72 / 100
On day 3, number of treated patients: 76 / 100
On day 4, number of treated patients: 67 / 100

Scenario 3

- num_nurses = 20
- num_shifts = 3
- num_days = 15
- num_patients = 150
- max_treatment_duration = 15 # in 10 minutes chunks
- max_working_time = 8 * 60 # in minutes

Result

On day 0, number of treated patients: 127 / 150
On day 1, number of treated patients: 131 / 150
On day 2, number of treated patients: 134 / 150
On day 3, number of treated patients: 130 / 150
On day 4, number of treated patients: 130 / 150
On day 5, number of treated patients: 131 / 150
On day 6, number of treated patients: 133 / 150
On day 7, number of treated patients: 130 / 150
On day 8, number of treated patients: 129 / 150
On day 9, number of treated patients: 128 / 150
On day 10, number of treated patients: 133 / 150
On day 11, number of treated patients: 122 / 150
On day 12, number of treated patients: 124 / 150
On day 13, number of treated patients: 131 / 150
On day 14, number of treated patients: 130 / 150

Scenario 4

- num_nurses = 50
- num_shifts = 3
- num_days = 8
- num_patients = 500
- max_treatment_duration = 12 # in 10 minutes chunks
- max_working_time = 8 * 60 # in minutes

Result

On day 0, number of treated patients: 402 / 500
On day 1, number of treated patients: 414 / 500
On day 2, number of treated patients: 416 / 500
On day 3, number of treated patients: 411 / 500
On day 4, number of treated patients: 431 / 500
On day 5, number of treated patients: 419 / 500
On day 6, number of treated patients: 422 / 500
On day 7, number of treated patients: 425 / 500

Scenario 5

- num_nurses = 50
- num_shifts = 3
- num_days = 20
- num_patients = 500
- max_treatment_duration = 6 # in 10 minutes chunks
- max_working_time = 8 * 60 # in minutes

Result

On day 0, number of treated patients: 500 / 500
On day 1, number of treated patients: 500 / 500
On day 2, number of treated patients: 500 / 500
On day 3, number of treated patients: 500 / 500
On day 4, number of treated patients: 500 / 500
On day 5, number of treated patients: 500 / 500
On day 6, number of treated patients: 500 / 500
On day 7, number of treated patients: 500 / 500
On day 8, number of treated patients: 500 / 500
On day 9, number of treated patients: 500 / 500
On day 10, number of treated patients: 500 / 500
On day 11, number of treated patients: 500 / 500
On day 12, number of treated patients: 500 / 500
On day 13, number of treated patients: 500 / 500
On day 14, number of treated patients: 500 / 500

On day 15, number of treated patients: 500 / 500
On day 16, number of treated patients: 500 / 500
On day 17, number of treated patients: 500 / 500
On day 18, number of treated patients: 500 / 500
On day 19, number of treated patients: 500 / 500