Targeting population to evaluate COVID-19 strategies based on activity behaviour

Semester project - Final presentation

Transport and Mobility Laboratory

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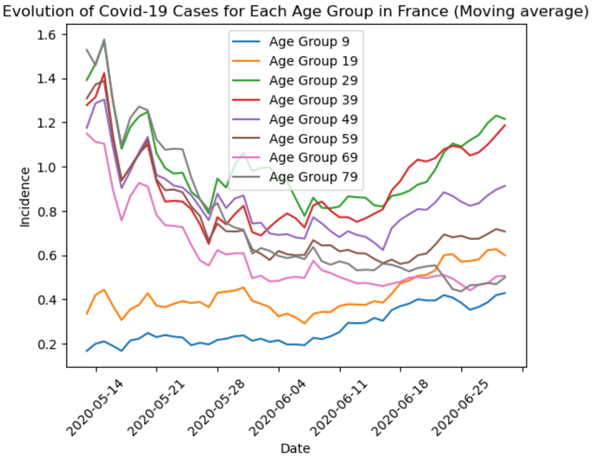
Motivation

Virus propagation differs through group segmentation, though restricting policies should depend on the group[1]

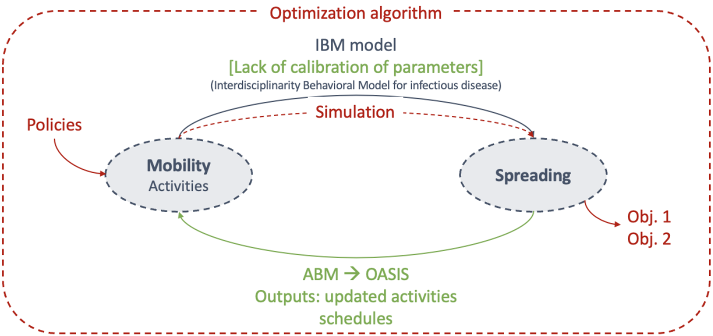


Project description

- Design a methodology to find **optimal targeted activity reductions**, reducing the epidemic spread and the economic impact of measures
- Restrictions target different segments of population: age, geographic areas,
- Combine ABM model with an optimizer
- Scientific literature:
  - Stochastic ABM for post-lockdown measures[2]
  - ABM Model for dynamic modeling of contagious disease spread[3]
  - Optimization of 2 loss-functions problems based on an ABM model, but not applied to mobility restrictions and epidemics[4]
  - Simulation of spreading of a virus using a synthetic population and a desagregated model[5]
  - Neural network to optimize restrictions policies in an SIR model[6]

[2] Hoertel 2020.
[3] Perez and Dragicevic 2009.
[4] Oremland and Laubenbacher 2014.
[5] Bissett KR 2021.
[6] C. Courtès 2022.

Scope of the project



- Scope of the project
- Available
- Further work

IBM model

- Disaggregated **agent-based model**: microscopic simulation[7]
- Models the **propagation of the virus** in the population according to geo-schedules, socio-economic and health data, and testing[8,9]
- Uses activity schedules of synthetic population with locations during a 30 min time-step (MATSIM)

[7] Axhausen and Gärling 1992.
[8] Cortes Balcells C. 2021.
[9] Cortes Balcells C. 2022.

Implementation of restriction policies

Since OASIS is not operational, we adapt the IBM model to add activity restriction policies

1. We define S activity-reduction scenarios
2. For each segmentation of the population $j \in [1, J]$, we select one restriction scenario $s_j \in [1, S]$
3. The restriction is applied at day T_{begin} and stops at T_{end}
4. Changes the activity schedules of people according to the chosen scenario, by replacing activities by "home"

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Optimization framework

The aim of the project is to find the best policies

We can write a two objective functions optimization problem to find the tradeoff between sanitary and economic costs

$$\underset{s, T_{begin}, T_{end}}{\text{minimize}} \quad \begin{bmatrix} \mathcal{L}_{eco}(s, T_{begin}, T_{end}) \\ \mathcal{L}_{sanitary}(s, T_{begin}, T_{end}) \end{bmatrix}$$

subject to:

$$0 < s_j \leq S$$
$$0 \leq T_{begin} \leq T_{end} \leq T_{sim}$$

N : number of scenarios
s_j : choice of scenarios for each segment
s : set of scenarios for each segment $(s_1, s_2, ..., s_J)$
T_{sim} : number of days simulated

Modeling the sanitary impact of the disease

Sanitary loss function :
We simulate the spread of the pandemic, and aim to reduce the number of dead people and infections by applying policies

$$\mathcal{L}_{sanitary} = C_{casualties}(s, T_{begin}, T_{end}) + \kappa \sum_{\tau=1}^{T_{sim}} I_\tau(s, T_{begin}, T_{end}) \tag{1}$$

$C_{casualties}$: Number of casualties during the simulation
T_{sim} : Number of days simulated
I_τ : Number of infected people on day τ
κ : Importance of number of infected people[10] ≥ 0

[10] We could consider the proportion of severe forms of Covid

Economic modeling

We model the economic impacts of the pandemic and restrictions. We take inspiration from the works from Shami and Lazebdnik.[11]

Cost of policies: number of remote-working periods due to restrictions. Some activities are less efficient at home, or impossible.

$$\mathcal{L}_{eco}(s, T_{begin}, T_{end}) = \epsilon\psi(T_{end} - T_{begin}) \sum_{i=1}^{k} \alpha_i H_i(s) \tag{2}$$

α_i : economic loss due to restrictions for activity i
$H_i(s)$: number of hours of activity i modified due to policies
ϵ : proportion of remoteless works/activities
ψ : reduction of efficiency working at home

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[11] Shami and Lazebnik 2022.

Optimization tools

Several heuristic methodologies could be used to solve this problem

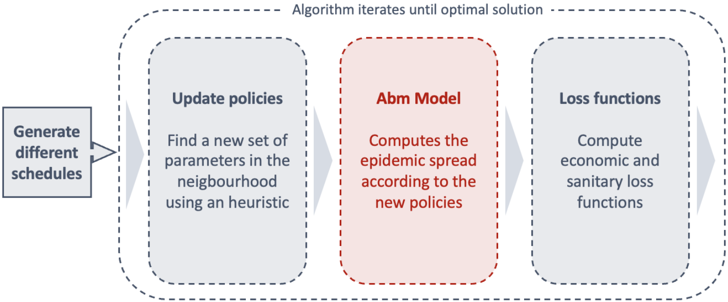
These optimization methods can be used to solve a bi-objective loss function, with a black-box model loss function.

- **Variable neighbourhood search**[12]
- Bi-Criterion Optimization with Multi Colony Ant Algorithms[13]
- Generation of the trade-off limits for multi-objective Pareto front[14]
- Simulated annealing[15]

[12] Mladenović and Hansen 1997.
[13] Iredi, Merkle, and Middendorf 2001.
[14] Mueller-Gritschneder, Graeb, and Schlichtmann 2009.
[15] Lin et al. 2008.

Optimization process

We use a meta-heuristic algorithm to find the optimal set of policies, minimizing both loss functions. We change the schedules at each iterations

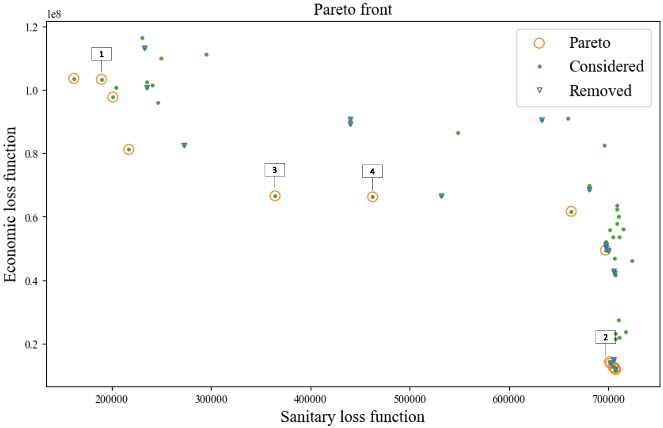


Implementation and optimization

- 4 mutually exclusive scenarios:
  1. Scenario 1: 0% activity reduction for work, 80% for all other activities
  2. Scenario 2: 20% reduction for all activities
  3. Scenario 3: 60% reduction for all activities
  4. Scenario 4: 0% activity reduction for education, 80% for all other activities
- Age segmentation: every 10 years - 9 segments
- Modeling the spread on Vaud, during 2 months
- Algorithm: VNS, using the python library Biogeme[16]
- Choice of hyperparameters: Modeling parameters

[16] "Biogeme 3.2.11 python package" 2018.

Pareto Front of the solutions



Evolution of infections according to the policies

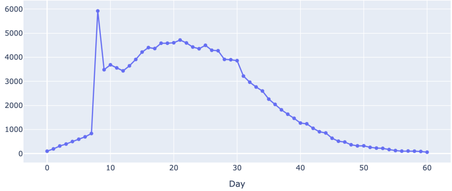


Figure: Pareto solution n°1

- Higher economic loss (105M CHF)
- Lower sanitary loss (200k infected.day)
- Restrain work for 30-39 yo.
- 60% restrictions for 50-59 yo.
- Restrictions during whole period.

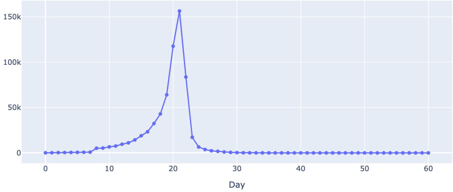


Figure: Pareto solution n°2

- Lower economic loss (15M CHF)
- Higher sanitary loss (700k infected.day)
- Restrain activities for 70-79 yo
- Less restrictions that Pareto solution n°1
- Start on day 1, end on day 59

Evolution of infections according to the policies

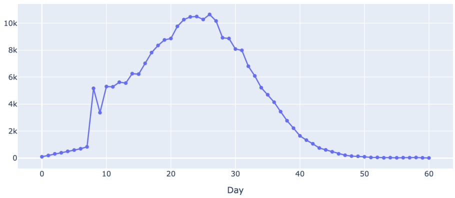


Figure: Pareto solution n°3

- Moderate economic loss (72M CHF)
- Moderate sanitary loss (360k infected.day)
- Restrain work for 30-39 yo.
- Start on day 2, end on day 59

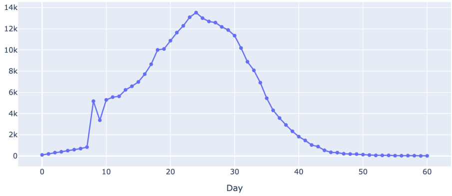


Figure: Pareto solution n°4

- Moderate economic loss (69M CHF)
- Moderate sanitary loss (460k infected.day)
- Restrain work for 40-49 yo.
- 20% restrictions for 70-79 yo.
- Start on day 2, end on day 59

Conclusion on findings

1. All policies are applied on the **longest possible time-span**: policies makers need to anticipate and act quickly
2. Most Pareto policies chose to keep **work and education**, which have the higher economic costs
3. Model seems to be **consistent**: more reductions reduces the sanitary cost, but increases economic cost
4. **Calculation time**: 6 hours on Jed Server, 800k people, 2 months period, to get 15 Pareto points.

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Further improvements

1. Segmentation on other factors : geographic (urban, rural)
2. Reduce number of segments
3. Simulate on Switzerland and for a longer period, 8M people
4. Implement several restrictions periods
5. Improve calibration of hyper-parameters
6. Implement OASIS to adapt schedules to the epidemic spread

Questions and comments

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We model the economic impacts of the pandemic and restrictions. We take inspiration from the works from Shami and Lazebdnik.[17]

$$\mathcal{L}_{eco} = C_{Death} + C_{Infected} + C_{Policies} + C_{Healthcare} \tag{3}$$

C_{Death} : Loss of production (GDP) encountered by the death of people
$C_{Infected}$: Reduction of productivity for infected people
$C_{Policies}$: Cost of implementing the policies (activities changed to 'home')
$C_{Healthcare}$: Healthcare system costs increase with disease

[17] Shami and Lazebnik 2022.

Discounted contribution to GDP between age of death and age of retirement :

$$C_{Death} = GDP_{year} \sum_{i \in D_{sim}} (A_{retirement} - A_i) \tag{4}$$

Reduction in GDP due to infection :

$$C_{Infected} = GDP_{day} \delta \sum_{\tau=1}^{T_{sim}} \sum_{i \in D_\tau} \mu_i \tag{5}$$

D_{sim}	: Set of dead people during the simulation
A_i	: Age of death of agent *i*
$A_{retirement}$	: Average age of retirement in Switzerland
GDP_{day}	: Average individual daily contribution of GDP
D_τ	: Set of agents that begin to be infected on day τ
μ_i	: Number of days of recovery for agent *i*
T_{sim}	: Duration in days of the simulation
δ	: proportion of work that can not be done during infection

Cost of policies: number of remote-working periods due to restrictions. Some activities are less efficient at home, or impossible.

$$C_{Policies} = \epsilon\psi(T_{end} - T_{begin})\sum_{i=0}^{k}\alpha_i N_i \tag{6}$$

α_i : economic loss due to restrictions for activity *i*
N_i : number of hours of activity *i* modified due to policies
ϵ : proportion of remoteless works/activities
ψ : reduction of efficiency working at home

Cost of healthcare system due to the pandemic. We model the cost of the healthcare system due to the pandemic as being proportionate to the number of severe forms of Covid-19.

$$C_{Healthcare} = \zeta \sum_{\tau=1}^{T_{sim}} H_\tau \quad (7)$$

and :

$$H_\tau = \nu I_\tau \quad (8)$$

where:

- T_{sim} : Number of days simulated
- ζ : Average cost of healthcare by infected people at hospital, for period of infectic
- H_τ : Number of new-hospitalized people at day τ
- I_τ : number of new infected on day τ
- ν : Pourcentage of severe forms

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Choice of hyperparameters

Hyperparameter	Chosen	Source
Average remaining working years	20 years	Vd.ch
Cost healthcare	4700 CHF/day	Statistica
Pourcentage of severe forms	10%	Educated guess
Pourcentage of death	5%	Educated guess
Normal GDP Vaud	62 Mds CHF	Vd.ch
Population Vaud	814 000 hab.	Vd.ch
Proportion of remote-less works	50%	Educated guess
Proportion of work that can not be done during infection	40%	Educated guess
Reduction of efficiency working at home	20%	Educated guess
Initial infections	+100/day for 8 days	Modeling choice
Simulation length	60 days	Modeling choice

Activity	Economic loss	Source
Work	344 CHF/day/hab.	PIB/Population/225 Working days
Leisure	30 CHF/day/hab.	Educated guess
Home	0 CHF/day/hab.	Educated guess
Shop	40 CHF/day/hab.	Educated guess
Education	344 CHF/day/hab.	Same importance as work
Other	40 CHF/day/hab.	Educated guess

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