Assessing the effectiveness of perimeter lockdowns at the urban scale: the case of Madrid

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Background

Epidemiological context

Second wave of COVID-19 building up (September 2020).

Socioeconomic context

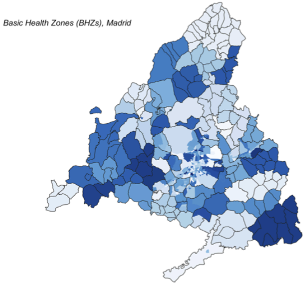
- Madrid wanted to avoid hard generalized lockdown, emergency state and any imposition from Central Government.
- Want to avoid "economic ruin" and sought for softer alternatives.

"Madrid belongs to everyone. Madrid is Spain inside Spain. What is Madrid if not Spain?" - Isabel Díaz de Ayuso, President of Autonomous Community of Madrid.

The strategy: Perimeter lockdowns for Basic Health Zones

What are they?

PLs: Cut down mobility in-and-out of areas under risk
BHZs: minimal areas with basic public health support.



from García-García et al. (2022)

- First round of lockdowns: Sep 23.
- 37 BHZs affected in the whole region.
- Time extension: 14 days or more...
- Prerrequisites?
  - 14 days cumulative incidence rate above 1000 cases per every 10^5 inhabitants.
  - Increasing trend.
  - Observation of community spread.

Framing the problem

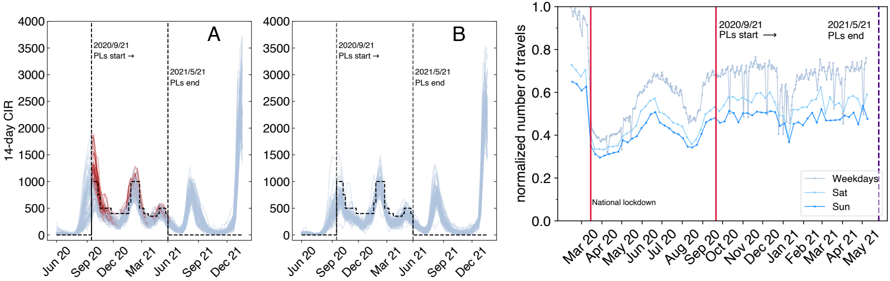
Question

Is this a good control strategy?

Our work and aims

- Qualitative inspection of epidemiological data from Madrid.
- Devise a general, minimal and mechanistic model of perimeter lockdowns.
- Explore under which circumstances could work.

Inspection of real data

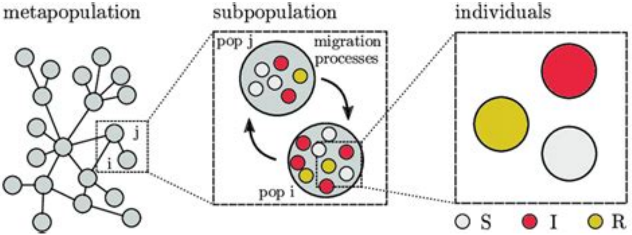


- Peak incidence & activation occurs around same time in 1st round.
- Literature confirmed that measures had no real effect.
- Threshold criterion? Moving like waves & some free zones above it.
- Highly synchronized time series + No meaningful effect on mobility.

$\longrightarrow$ Seems like a dubious realization of the strategy.

Framework: Network metapopulation

We built a data-driven metapopulation model for Madrid.



from Colizza & Vespignani (2008)

System: Nodes are entire populations and edges mobility are flows.
Epidemic: Homogeneous-mixing SIR within nodes.
Mobility: origin-destination matrices with real data from a pre-COVID-19 reference period.
Mobility parameter κ to control baseline flows ($\kappa \to 0$ no one moves).

More modeling details

Response: How are perimeter lockdowns implemented?

- 14-day cumulative incidence rate per 10^5 inhabitants as the monitoring variable.
- Set a risk threshold Θ. If 14d CIR $> \Theta$ in a district i: we activate perimeter lockdowns.
  - Mobility: $\kappa_{ij} = \kappa_{ji} = 0$ for i and $\forall j$.
  - Local transmission rate reduction fraction χ_i so that $\beta_i = \chi_i \beta$, where $\beta = R_0 T_I$.
- Below threshold districts: $\kappa \neq 0$, $\chi = 1$ (nothing happens).

Parameters:

- $R_0 = 1.25$ ($<$ COVID-19's)

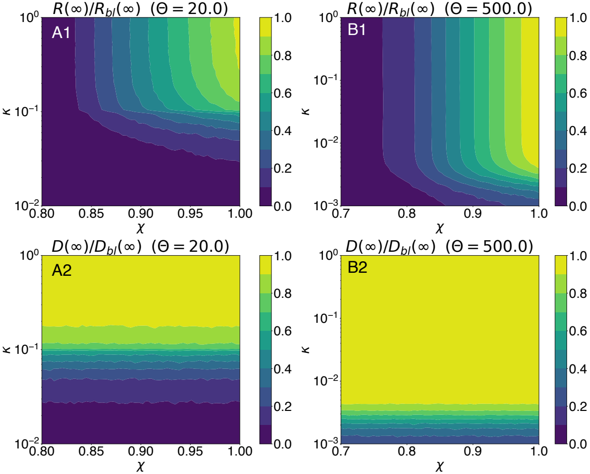
Observables:

- Final prevalence.
- Fraction of locked districts.

(both quantities normalized to baseline scenario: unmitigated spreading)

Results: Hard to avoid a generalized lockdown

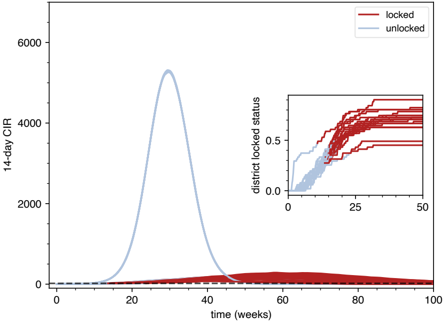
Left: Proactive strategy ($\Theta = 20$). Right: Reactive strategy ($\Theta = 500$).



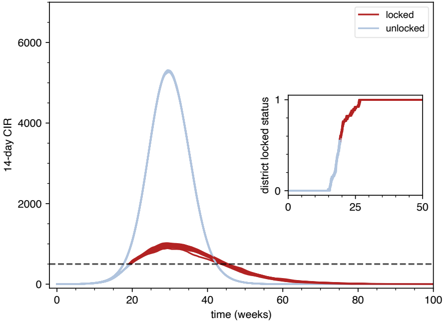
- Reducing χ the most effective thing. (Hard to achieve?)
- Mobility κ? Does nothing until ridiculously low values!

Results: Local outbreaks highly synchronized

Left: Proactive strategy ($\Theta = 20$).



Right: Reactive strategy ($\Theta = 500$).



- Doing something better than nothing (indeed).
- Local outbreaks are highly synchronized.

Conclusions

Take-home messages:

- Urban scale → Small and well-interconnected systems → outbreaks highly synchronized.
- If aim is to protect some parts of the system...
- Lockdowns have to be activated unrealistically soon and tight.
- Restricting mobility by itself does nothing.

Limitations (good and bad for the strategy's fate):

- SIR is too simplistic but it is a best-case scenario.
- Measures are activated instantaneously and with absolute compliance.
- Homogeneous-mixing at district level (future works).
- Markovian mobility and too-coarse resolution (future works).

THANKS FOR YOUR ATTENTION!

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Quick literature review

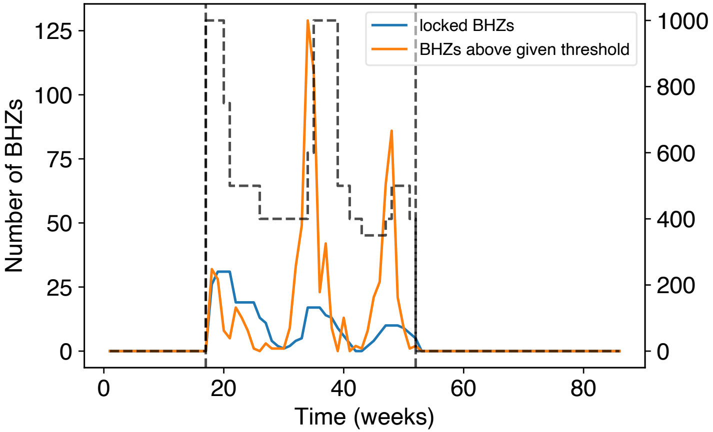
Santiago de Chile [Li et al. (2021)]:

- "localized lockdowns on their own are insufficient to control pandemic growth in the presence of indirect effects from contiguous neighboring areas that do not have lockdowns."
- "the epidemic is only controlled when generalized lockdowns are in place."

Madrid:

- Candel et al. (2020). (et al: includes Madrid's Public Health vice counselor) Tell and sell their management of the COVID-19 situation.
- Fontán-Vela et al. (2021): "According to our analysis, the decrease in the epidemic curve started before the impact of the perimeter lockdown could be reflected."
- García-García et al. (2022): "Our analysis suggests that the perimeter closures by Basic Health Zone did not have a significant effect on the epidemic curve in Madrid."
- Replies to Candel et al. (2020) harshly criticizing the *propaganda*.

Number of BHZs above threshold



- Apart from the strange moving threshold criterion...
- Huge number of free BHZs above threshold during successive waves (3rd and 4th global waves).

Epidemic model

Within each subpopulation the following reactions take place:

$$S + I \rightarrow I + I \tag{1}$$

with probability $P_i(S \rightarrow I) = 1 - (1 - R_0/(T_I N_i))^{I_i}$,

- R_0 is the basic reproduction number of the disease,
- T_I is the mean infectious time,
- N_i stands for the number of individuals in patch i, and
- I_i accounts for the number of infected individuals in such region.

$$I \rightarrow R \tag{2}$$

with probability $P(I \rightarrow R) = 1/T_I$.
New cases stochastically sampled from binomial distributions.
Process iterated with $\Delta t = 1$ day until absorbing state reached ($I = 0$).

Mobility model

Several approaches exist:

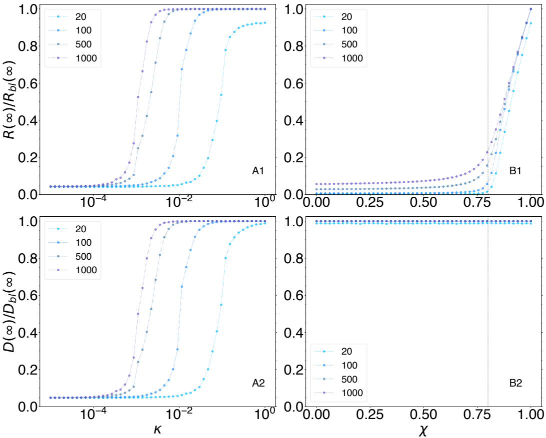
- Simple random walks assigning equal probability to traveling to any neighboring subpopulation.
- Degree-based travel, gravity, radiation models.
- Micro-mobility models (EPR and extensions).

Our approach here is fully data-driven:

- Data from mobility survey carried by the Spanish Ministry of Transport, Mobility and Urban Agenda. (https://www.mitma.gob.es/ministerio/covid-19/evolucion-movilidad-big-data)
- Build OD matrices **M**: elements contain flow of travelers from i to j.
- Diffusion rate matrices. New travelers are extracted from multinomial distributions following rates:

$$D_{ij} = \begin{cases} \kappa \frac{M_{ij}}{\sum_j M_{ij}} & \text{if } i \neq j \\ 1 - \sum_{k \neq i} D_{ik} & \text{if } i = j \end{cases} \tag{3}$$

Results: Phase diagrams



Left: fixed $\chi = 1$. Right: fixed $\kappa = 1$.

Θ: Restrictions should be activated very, very soon.

κ: Mobility does nothing (until unrealistically low values).

χ: Focus on transmissibility (but departed from already low R_0).