On Exit Strategy from Covid-19 Lockdown

Prof. Amnon Shashua, Prof. Shai Shalev-Shwartz

March 2020

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Three main models for handling the Covid-19 outbreak:

1 **Full lockdown**

2 **Precision quarantine-** Isolate positive cases and their immediate contacts using "contact tracing" technologies, until a vaccine/cure is available.

3 **Herd-immunity:** No need to wait for a vaccine; but, high mortality and health system might not contain the outburst

We propose a combination of both models:

Managed herd-immunity with the RISK-BASED MODEL (1+2+3)

- High-risk group → 1
- Low-risk group → 3

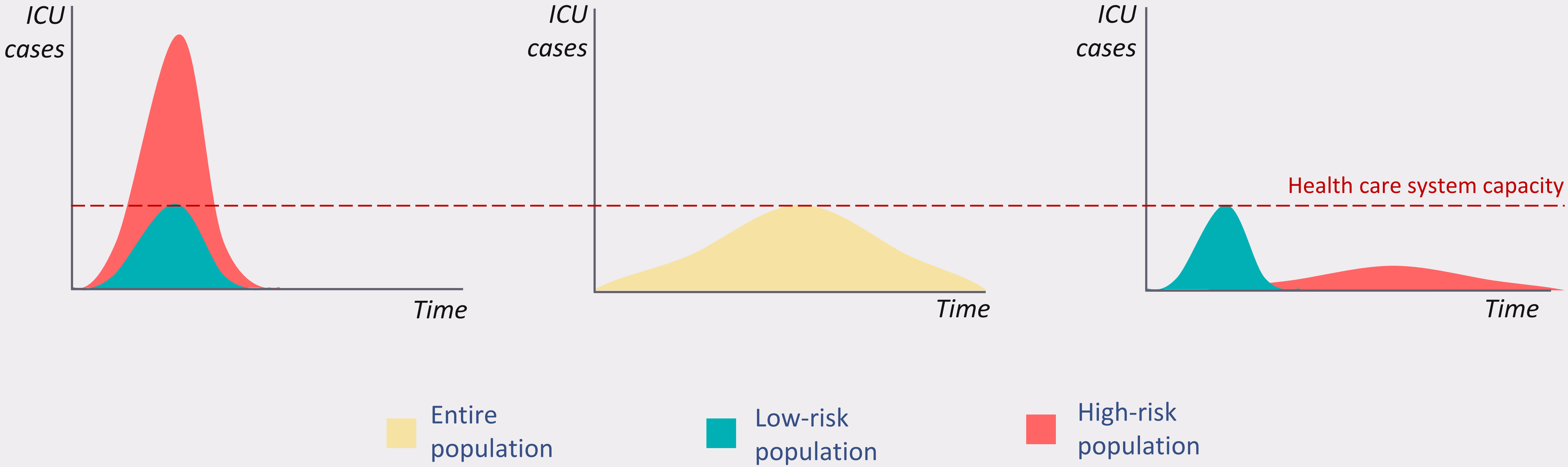
Second phase → High-risk group is gradually released 3+2

The Risk-based Model

Without any safety measures

Flattening the curve for the entire population

Risk-based model



Questions of Interest

- **Define “high-risk” group: age and pre-existing conditions cut-off**
  - How to determine without overfitting
- **Can the health system capacity (say, ICU beds) contain the number of severe cases among the low-risk group?**
- **Beyond obvious benefits to the economy, is the risk-based model safer in terms of overall mortality?**

Worst-case Analysis

→ **The problem:** Covid-19 dynamics (spread and duration) is too complicated at this stage

→ **The solution:** adopting worst-case analysis under reasonable assumptions

Worst-case analysis under reasonable assumptions

- Assumptions:
  + Upper-bound on the time from infection → ICU care- 1 weeks*
  + The probability of a low-risk person to be infected and need a critical-bed care is fixed.
    → Why: low-risk group release can be done under social distancing restrictions (to avoid viral load)
- Worst-case:
  + Infection rate among the low-risk group will be 100%
  + All severe cases among the low-risk group will need ICU **simultaneously**

*research shows the average time is 5-7 days

Analysis

- The analysis below focuses on the low-risk population.
- $m =$ size of the low-risk population
- $b =$ budget of ICUs

$$\mathbb{P}[\text{severe}] = \mathbb{P}[\text{severe} \;\wedge\; \text{infected}] \;=\; \underbrace{\mathbb{P}[\text{infected}]}_{\leq 1} \; \underbrace{\mathbb{P}[\text{severe} \,|\, \text{infected}]}_{:=\nu}$$

Therefore, we need:

$$b \;\geq\; m\,\nu \;.$$

- Our goal is to derive an upper bound on ν

Upper bounding ν

$$\nu \;:=\; \mathbb{P}[\text{severe} \,|\, \text{infected}] \;\approx\; \frac{\#\text{ severe today}}{\#\text{ infected today}}$$

- We know $k := \#$ severe today
  (and to be on the safe size, "today" should be in the time interval $[0, \text{one week}]$)
- We don't know $\#$ infected today
- Let $p^* =$ probability to be infected *today*, then

$$\nu \approx \frac{k}{\#\text{ infected today}} \;=\; \frac{k}{p^*\, m}$$

- So, to prove $b \geq m\,\nu$ we need

$$b \geq m\,\nu \approx \frac{k}{p^*}$$

- We now need a lower bound on p^*

Lower bounding p^*

- By sampling n i.i.d. persons from the low-risk population and finding S_n cases, we have $p^* \approx \frac{S_n}{n}$
- Overall:

$$b \geq m\,\nu \;\approx\; \frac{k}{p^*} \;\approx\; \frac{k}{S_n/n}$$

- Example: in Israel, we have $k = 15$ and we estimate $p^* = 0.02$ so we need $b \geq 750$
- But, all of the above involved approximations. We need bounds that hold with sufficient probability!

Tail bounds

We derive concrete bounds based on the following techniques (and some tricks):

- Bernstein's inequality: If $S_n \sim \mathrm{Binom}(p, n)$ then

$$\mathbb{P}[S_n - np > t] \;\leq\; e^{-\frac{t^2/2}{np(1-p)+t/3}}$$

- Zubkov and Serov 2013:

$$\mathbb{P}[S_n \leq k] \leq \Phi\left(-\sqrt{2nD_{KL}(p,(k+1)/n)}\right)$$

  where Φ is the cumulative distribution function of a standard normal variable and D_{KL} is the KL-divergence

Results

Recall, we need

$$b \;\geq\; m\,\nu$$

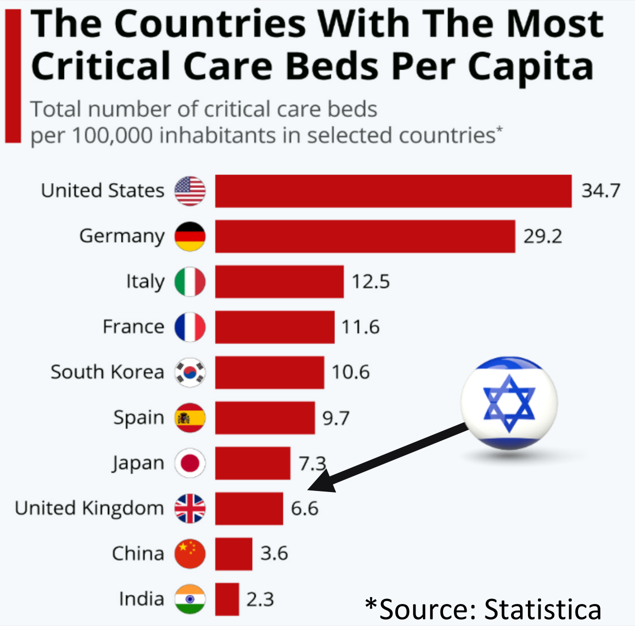
For sufficiently large sample size n, with high probability we have

$$m\,\nu \;\geq\; 1.92\,\frac{k}{S_n/n}\;.$$

Israel as a Case Study

As of 3/29/20:

- $k \le 15$
- p^* indications
  - **1%-** pre-outburst situation in Iceland
  - **1.8%**- medical crew sampling in Jerusalem
  - **8%**- Partners Health, Boston
  - We assume **2%**
- p^* can be estimated with a relatively small i.i.d. sampling



Required # of ICU beds

Low-risk group severe cases that require ICU

$$b > \frac{1.6k}{p^*}$$

Current % of positive cases among the low-risk population

$$b > \frac{1.6 \cdot 15}{0.02}$$

$$\boldsymbol{b > 1200}$$

12 ICU beds per 100K population

Should be manageable

Summary

Risk-based model	Precision quarantine
• High infection rate among low-risk group → **low mortality** • Low infection rate among the high-risk group thanks to herd-immunity of the rest	• Unified infection rate among the entire population → **high mortality** among high-risk group
• Minor negative effect on the economy	• Extensive negative effect on the economy
• Clear exit point- result in economic stability and higher civilian cooperation	• Lack of visibility- result in economic instability and civilian despair
• Short duration and controlled effect on the health care system	• Devastating and prolonged effect on the health care system