Challenges and Opportunities for Complex Systems in a Global post-COVID-19 Society

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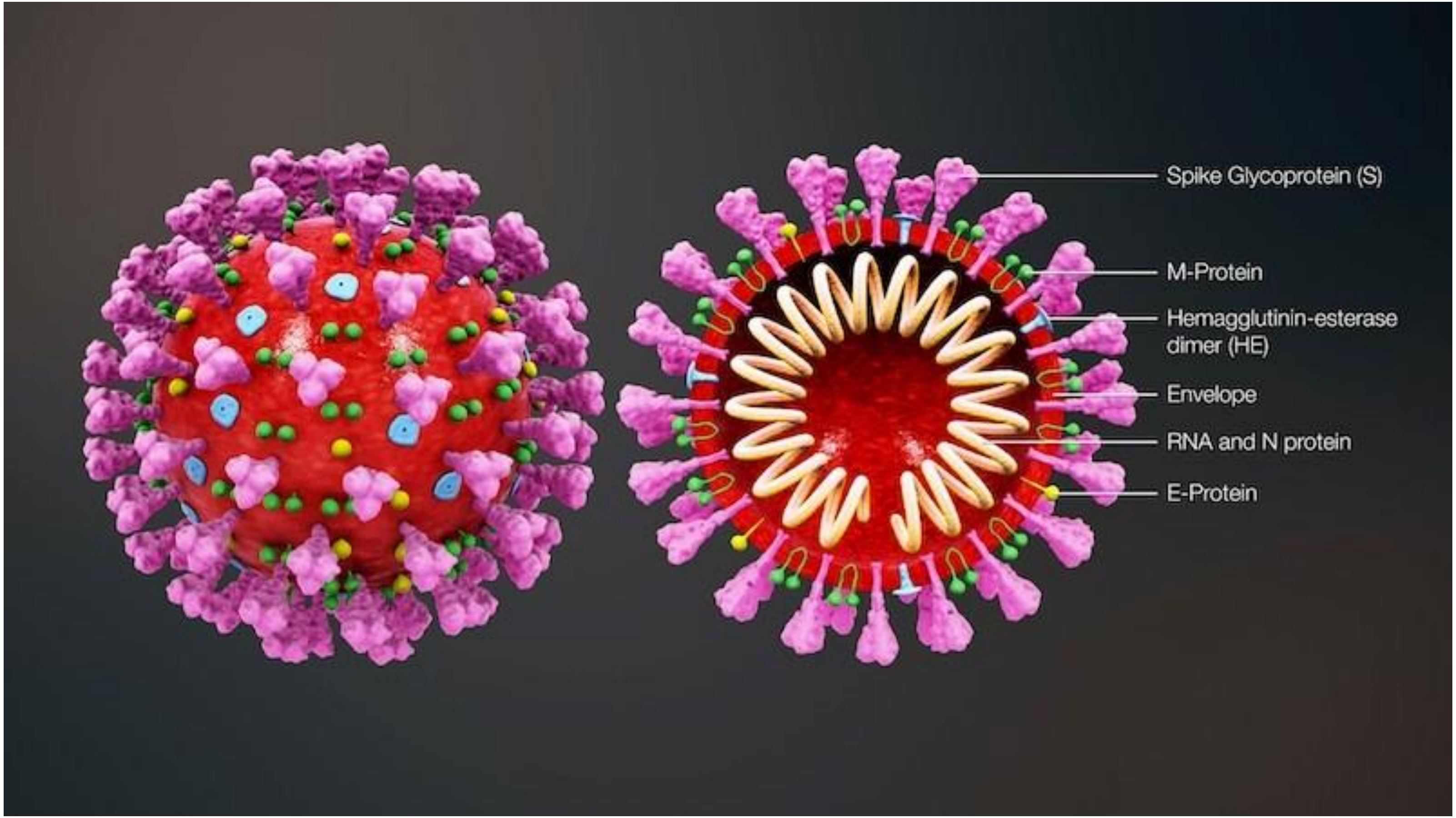
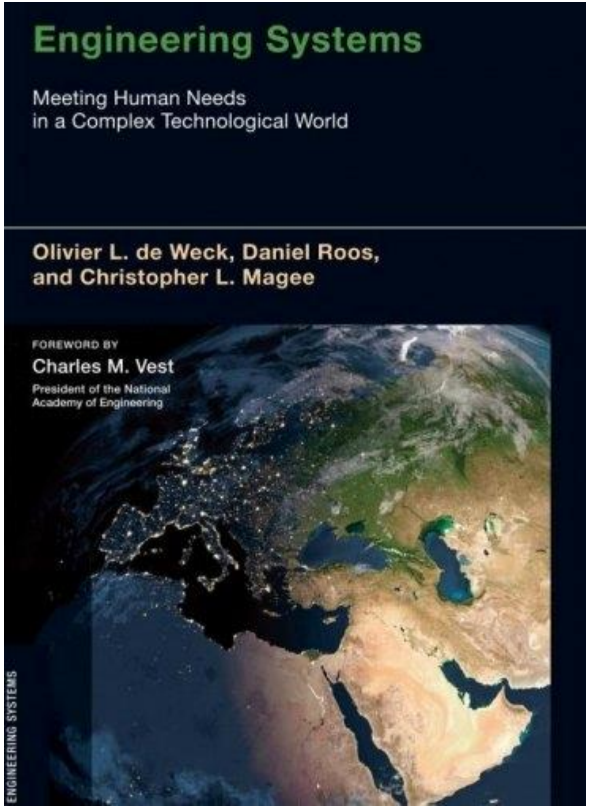


Image Source: http://sdcity.edu/about/communications/covid19/



de Weck OL, Roos D, Magee CL. *Engineering systems: Meeting human needs in a complex technological world*. MIT Press; 2011.

Engineering Systems

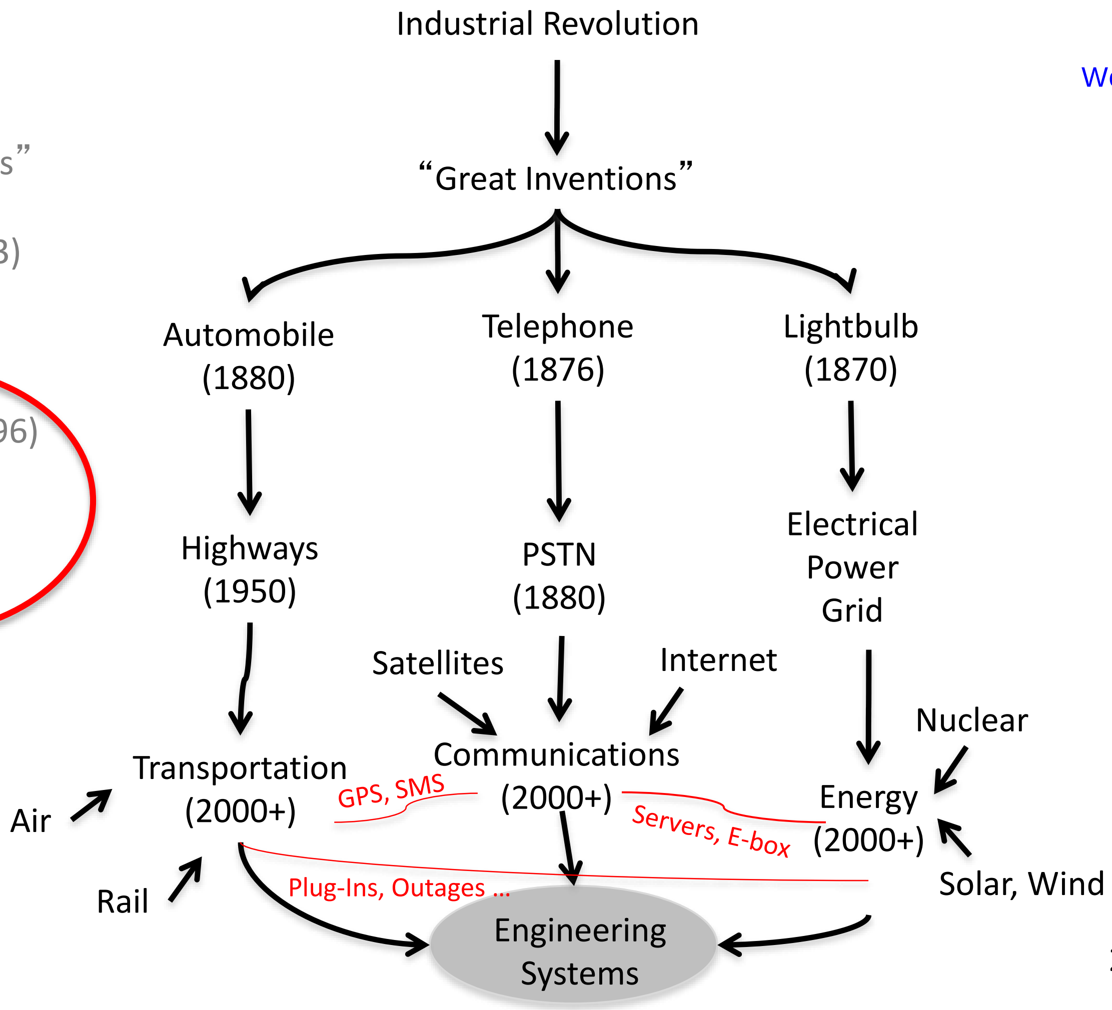
Engineering systems are characterized by a **high degree of technical and social complexity** and they aim at fulfilling important functions in society.

Other “spines”

Aircraft (1903)
Airports
Air Transport

Vaccines (1796)
Hospitals
Health Care
System

Etc…



Timeline

World Population

18th Century
0.7 Billion

19th Century
1 Billion

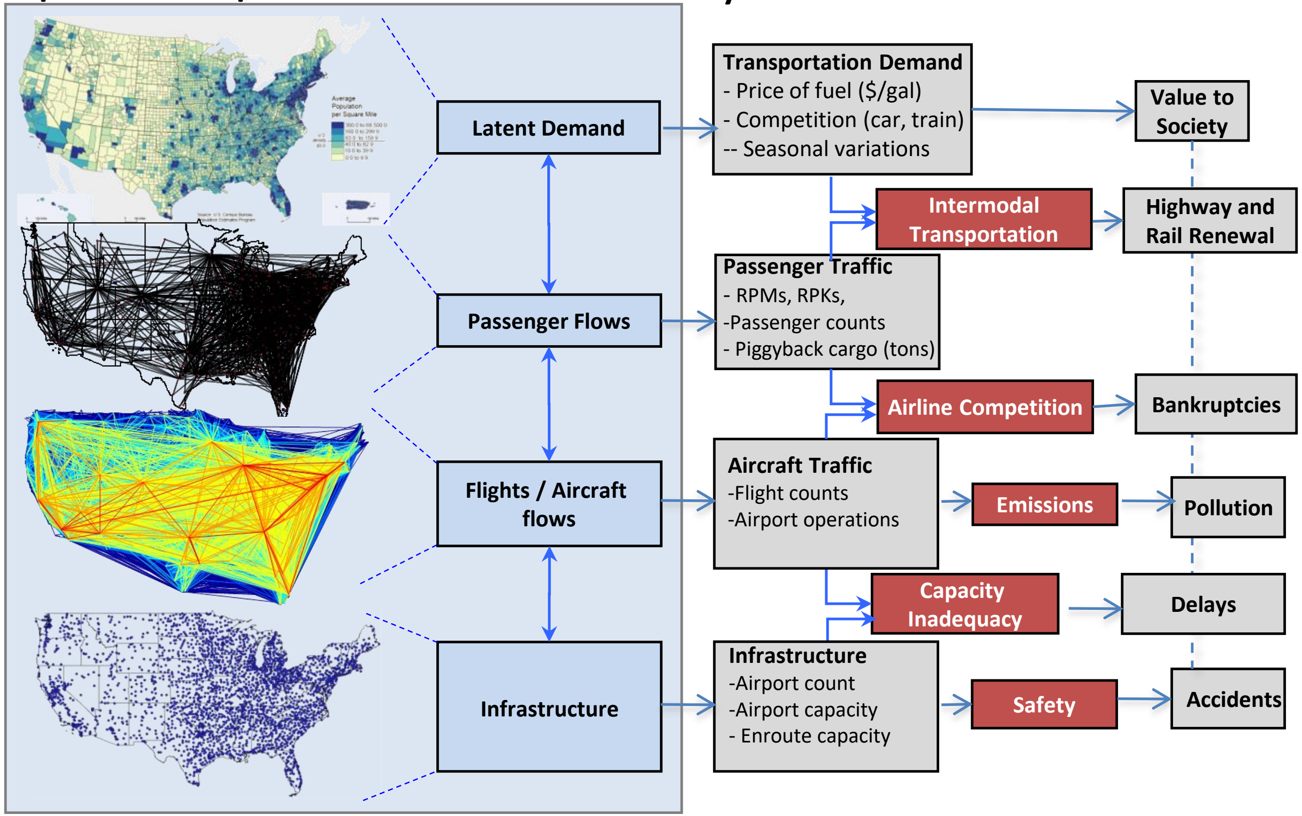
20th Century
2.5 Billion

21st Century
7.5 Billion

22nd Century ?
10+ Billion?

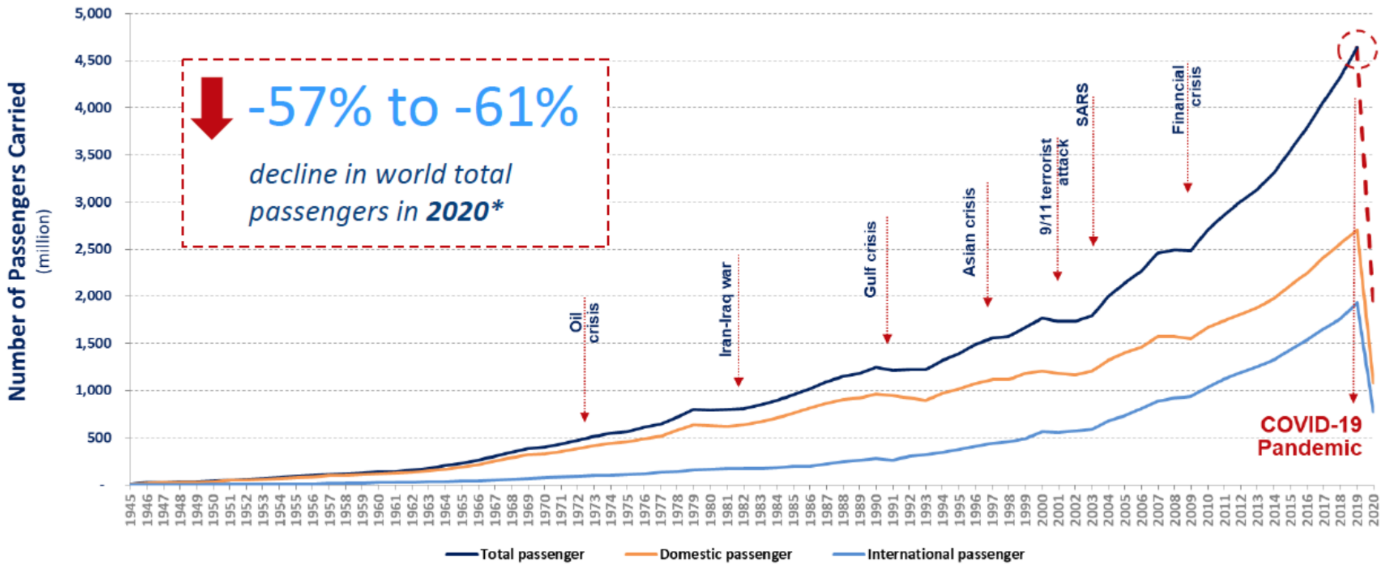
Air Transportation: A typical Engineering System

Spatial Decomposition | **System Performance and Other Issues**



Adapted from: Bonnefoy P. , "Scalability of the Air Transportation System and Development of Multi-Airport Systems: A Worldwide Perspective ", PhD Thesis, MIT, Engineering Systems Division, 2008

WORLD PASSENGER TRAFFIC EVOLUTION 1945 – 2020*



[ICAO 9-23-20]

~$395 billion loss in gross passenger operating revenue in CY2020

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REGULAR PAPER

WILEY

Handling the COVID-19 crisis: Toward an agile model-based systems approach

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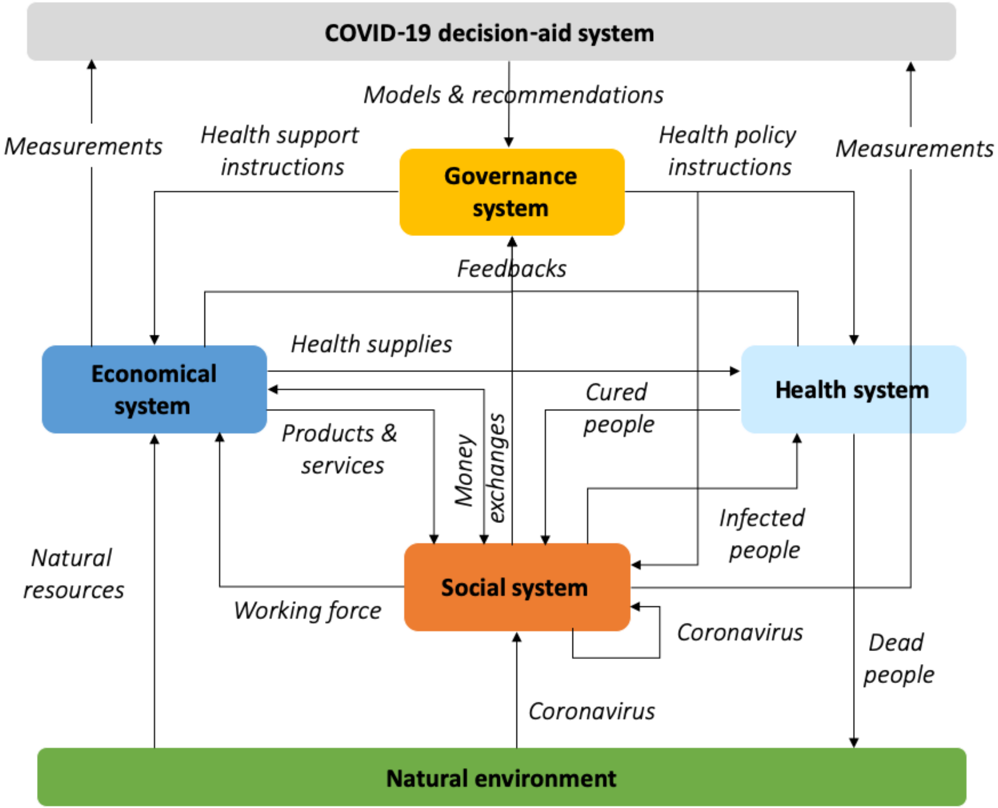
Abstract

The COVID-19 pandemic has caught many nations by surprise and has already caused millions of infections and hundreds of thousands of deaths worldwide. It has also exposed a deep crisis in modeling and exposed a lack of systems thinking by focusing mainly on only the short term and thinking of this event as only a health crisis. In this paper, authors from several of the key countries involved in COVID-19 propose a holistic systems model that views the problem from a perspective of human society including the natural environment, human population, health system, and economic system. We model the crisis theoretically as a feedback control problem with delay, and partial controllability and observability. Using a quantitative model of the human population allows us to test different assumptions such as detection threshold, delay to take action, fraction of the population infected, effectiveness and length of confinement

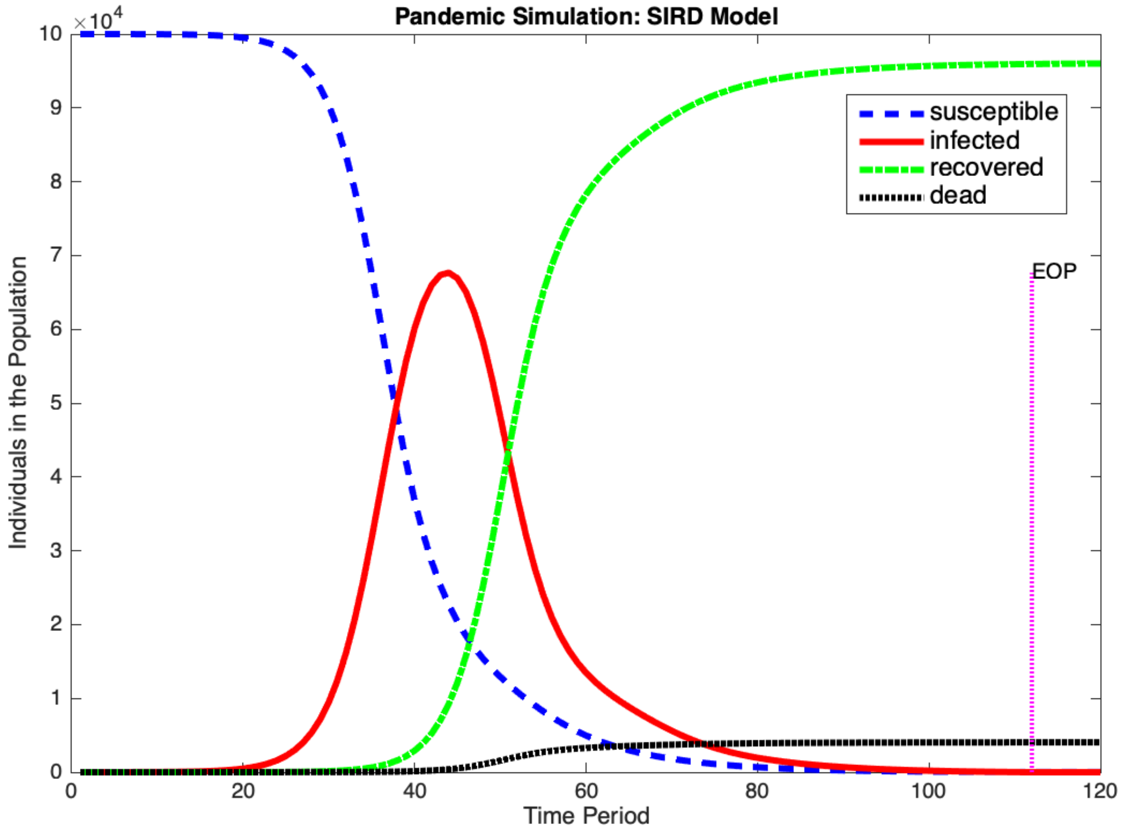
https://onlinelibrary.wiley.com/doi/full/10.1002/sys.21557

COVID-19 as a Complex System



de Weck O, Krob D, Lefei L, Lui PC, Rauzy A, Zhang X. Handling the COVID-19 Crisis: Towards an Agile Model-Based Systems Approach., Systems Engineering, Sept 2020

Classical Compartment Models: SIRD



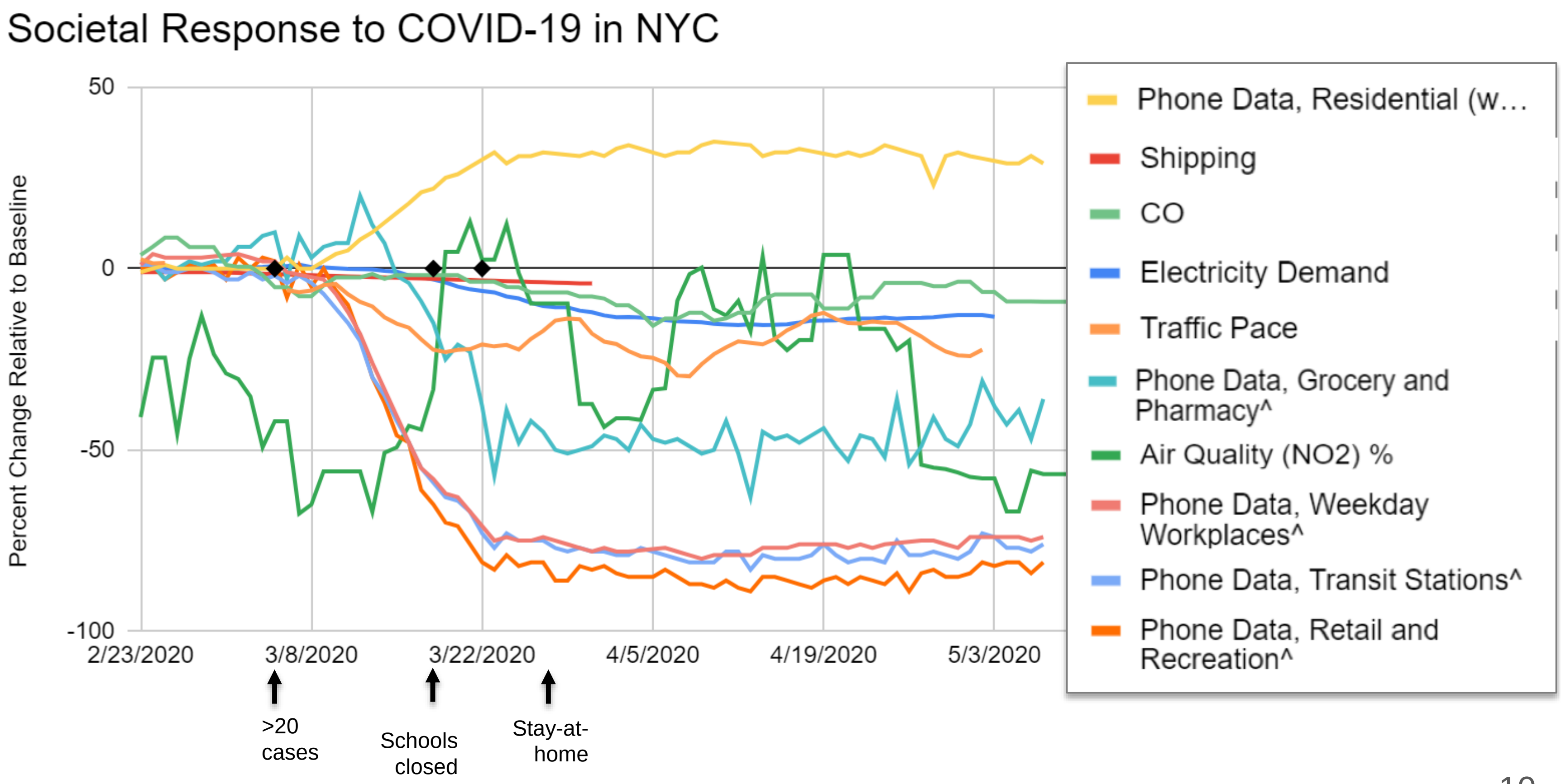
Scenario 0:
Population is modeled as a single compartment with a homogenous population where statistically everyone is equally likely to interact:

S – susceptible
I – infected
R – recovered
D – dead

Nominal Population Size: 100,000
10 average daily contacts
2.5 % propagation probability
Disease duration: 14 days
Lethality: 4%

No government intervention

Looking at the real numbers

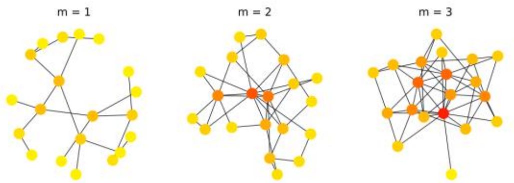


Source: Magliarditi, Morgan, Moraguez et al.

COVID-19 propagating across a Barabási-Albert social network

TABLE 1 Example of nodes distribution in a Barabási-Albert social network

Maximum degree	Cumulative proportion of nodes
2	0.05
3	0.43
4	0.62
5	0.73
10	0.91
20	0.975
100	0.999



https://en.wikipedia.org/wiki/Barab%C3%A1si%E2%80%93Albert_model

TABLE 2 Proportion π of the population that is infected, for different values of the propagation probability ρ. The value ν shows the number of simulations (out of 1000) that lead to a certain population infection threshold

ρ	π	ν	π	ν
0.005	$\pi < 0.1\%$	998	$1.7\% < \pi < 2\%$	2
0.010	$\pi < 0.1\%$	983	$21\% < \pi < 23\%$	17
0.015	$\pi < 0.1\%$	959	$43\% < \pi < 47\%$	41
0.020	$\pi < 0.1\%$	945	$58\% < \pi < 62\%$	55
0.025	$\pi < 0.1\%$	908	$70\% < \pi < 74\%$	92

TABLE 3 Lethality for different values of the reaction threshold τ and numbers of days of confinement γ

$\tau \setminus \gamma$	0	30	60	90	120	∞
0.01%	2.10%	1.32%	1.13%	1.08%	1.02%	0.98%
0.05%	2.10%	1.42%	1.35%	1.36%	1.35%	1.35%

COVID-19 Simulated Scenarios with SIRD compartment model

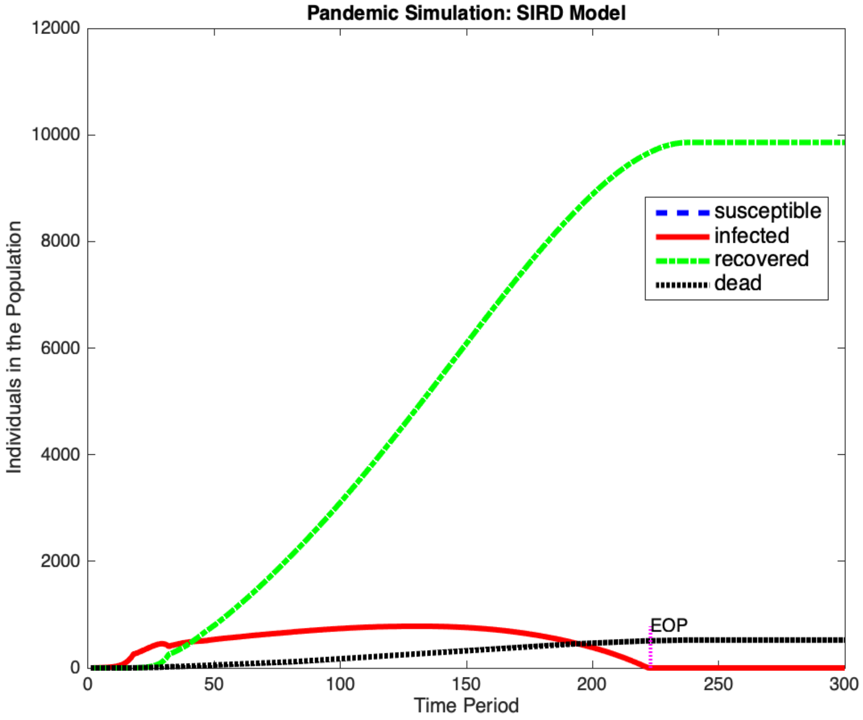
Scenario $N=10^5$	n	ρ %	τ %	ε	δ days	γ days	t days	total deaths	lost work $M	total damages $B
0	10	2.5	100	0	0	0	112	4060	312	4.38
1	10	2.5	0.01	0.66	20	30	179	4080	852	4.93
2	10	2.5	0.1	0.66	10	30	309	3989	950	4.95
3	10	1.5	0.05	0.66	20	60	286	3994	2106	6.1
4	10	2.5	0.05	0.8	5	30	334	3975	954	4.94
5	10	2.5	0.05	0.835	5	30	223	524	696	1.22
6	10	2.5	0.05	0.85	5	30	114	160	675	0.86
7	10	2.5	0.05	0.9	5	30	61	66	672	0.74
8	10	2.5	0.05	0.835	10	30	366	2904	858	3.76
9	10	2.5	0.05	0.835	15	30	312	3284	858	4.14
10	10	2.5	0.05	0.835	20	30	261	3505	806	4.31
11	5	2.5	0.05	0.835	20	30	88	190	674	0.86
12	5	1.25	10	0.835	20	30	201	1959	766	2.73

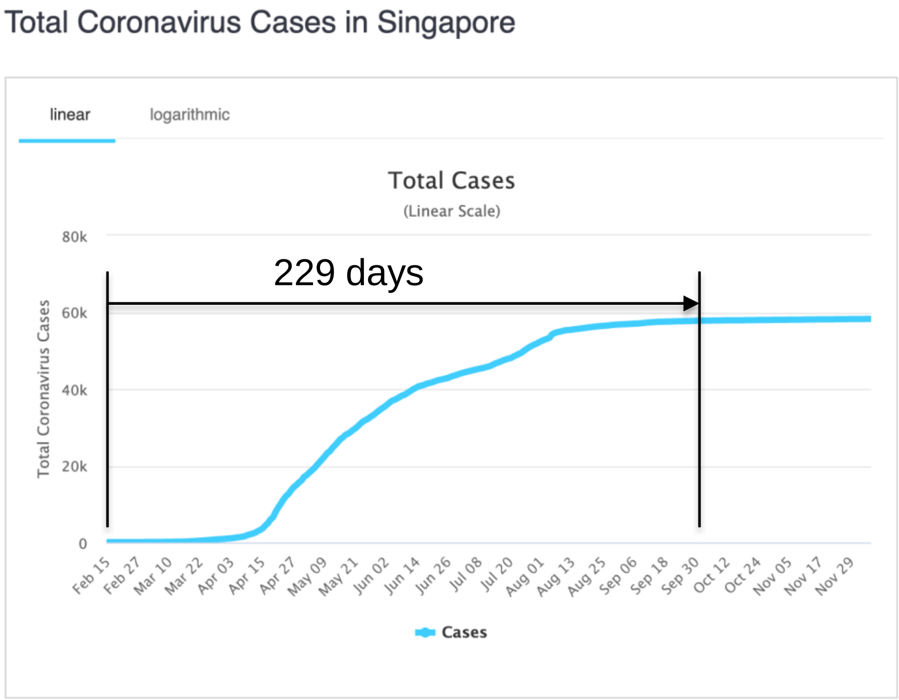
N=100,000 population size

Scenario analysis with SIRD model for assessing total human and economic damages:

n *number of daily contacts,* ρ *probability of infection,* τ *fraction of population infected to trigger confinement,* ε *fraction of population adhering to confinement,* δ *delay to confinement start,* γ *confinement duration,* **t** *duration of epidemic, total number of deaths, lost work in millions $M, and total damages including lost human lives and lost work in billions $B*

Response with strong intervention



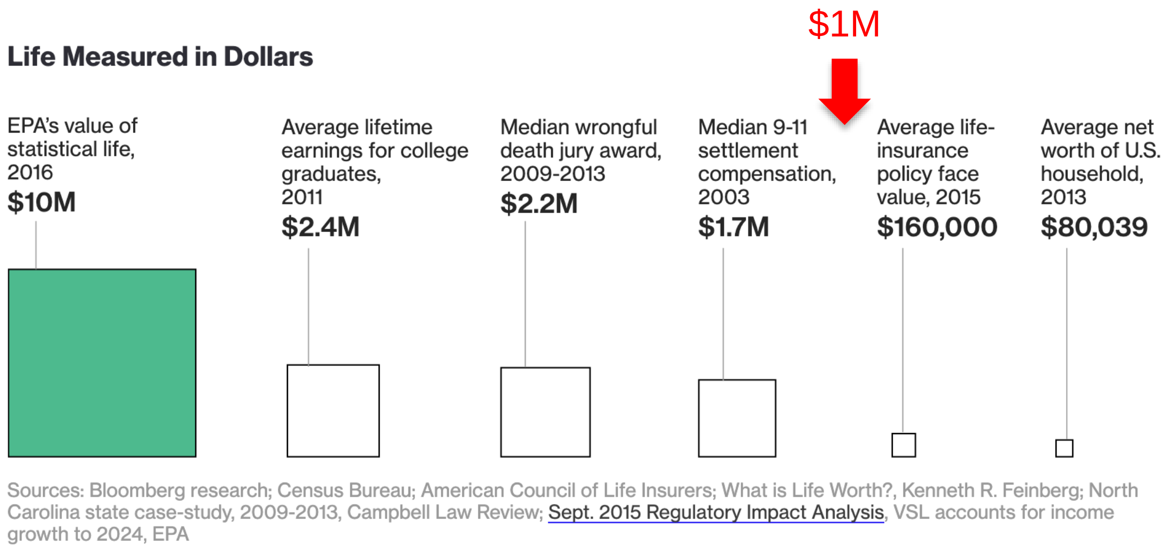


Scenario 5 Strong Government Intervention and high (but not perfect) compliance. Confinement: starts after 5 days, duration for 30 days, 83.5% compliance

Example: Singapore (population 5.6M)

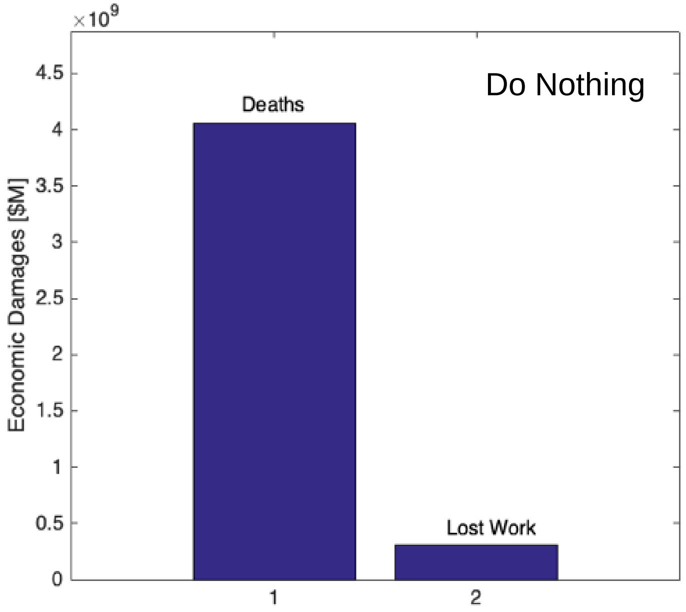
Value of a Human Life and COVID-19 Interventions

- Perhaps the biggest ethical issue around such tradeoffs is that it would require **placing an explicit economic value on human lives**, as discussed for instance in [34].
- The average value of a human life lost **is $1 million (in our paper).** This is a nominal assumption somewhere between the 3 years of GDP/capita/year recommendation made by the WHO for evaluating medical interventions at the low end (this would be about $200,000 based on the $63,000 GDP per capita in the U.S. in 2018) and the ~$8-10 million value of a statistical human life used by U.S. government agencies such as the Federal Aviation Administration (FAA) (or EPA) at the high end

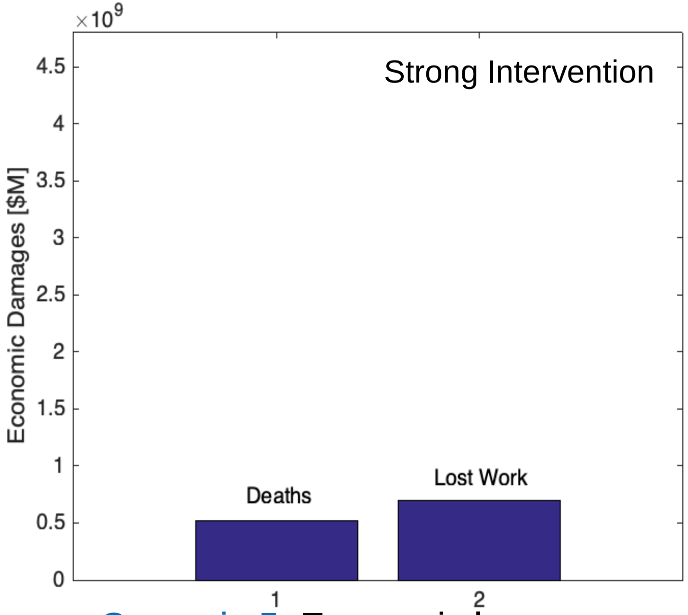


Source: https://www.bloomberg.com/graphics/2017-value-of-life/

Comparing Scenario 0 and 5 in terms of total losses



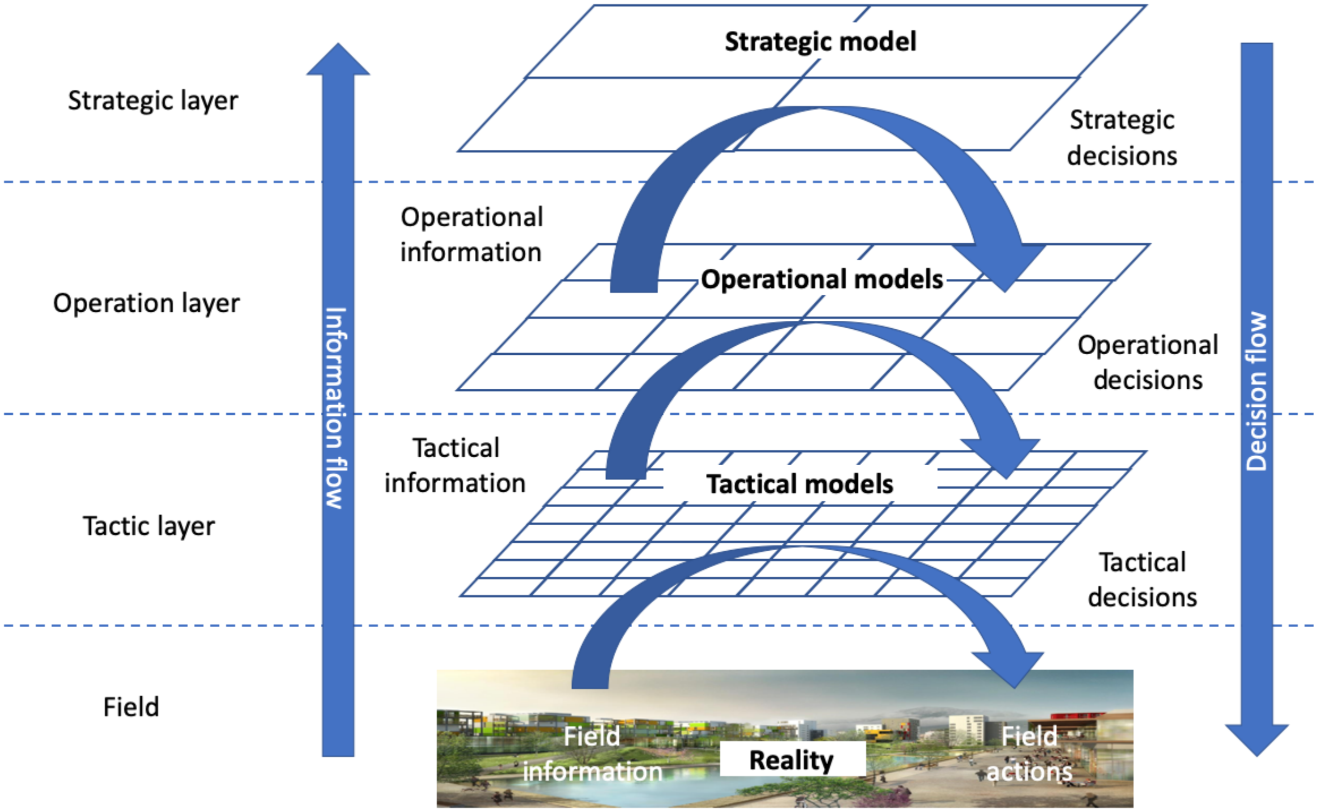
Scenario 0: Economic losses scenario 0 total $4.38B due to 4% lethality



Scenario 5: Economic losses scenario 5 total $1.22B with a lethality of 0.5%

[…] looking at the **total losses including the value of human lives lost** (valued at $1M each), scenario 5 only incurs 27.8% of the losses of the "do nothing" baseline. In order for a government to justify scenario 0 over scenario 5 it would have to **implicitly value a human life lost at less than $108,600** – only about 10% of the nominal value - which is the marginal difference in the economic loss of work divided by the difference in lives lost due to the epidemic

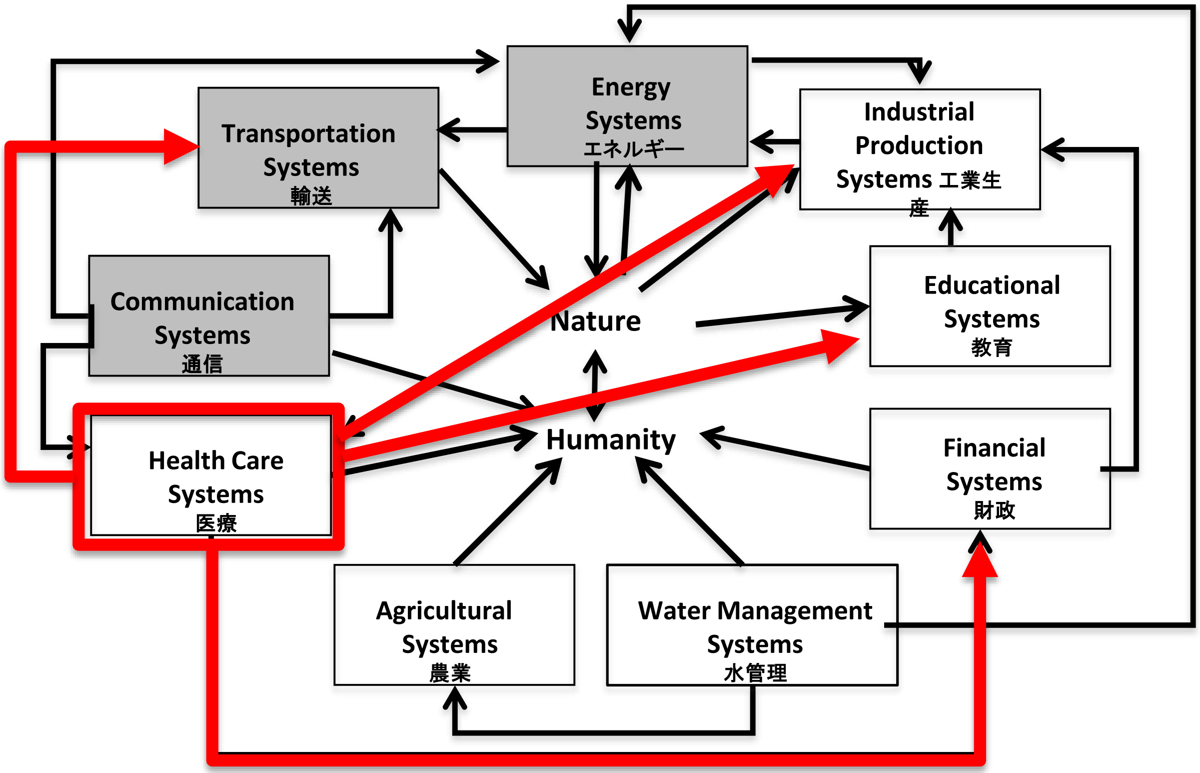
Message: We need a "C4ISR" systems for pandemic management



COVID-19 crisis, which is a *crisis of models*. The global community is indeed focusing on short-term health-specific models to better master the crisis, but these models are inadequate as soon as one wants to address the crisis from a longer-term society-wide perspective which requires systemic models.

F I G U R E 1 1
Proposal of generic systems architecture layers for a COVID-19 decision-aid system

Global System-of-Systems
大域的「システム・オブ・システムズ」



Winners and Losers post-COVID-19

- **Winners**
  - Vaccines and PPE
  - Sanitation and Cleaning Products
  - High Speed Mobile Internet Providers
  - Online Education
  - Personal Mobility (cars?)
  - Socially-distanced Tourism (e.g. RVs)
  - Grocery delivery services and takeout
  - Online Commerce

- Losers
  - Aviation (for now)
  - Classical Restaurants
  - Classical Hotels
  - Public Transportation
  - Events
    - Concerts
    - Movies
  - In-Person Education

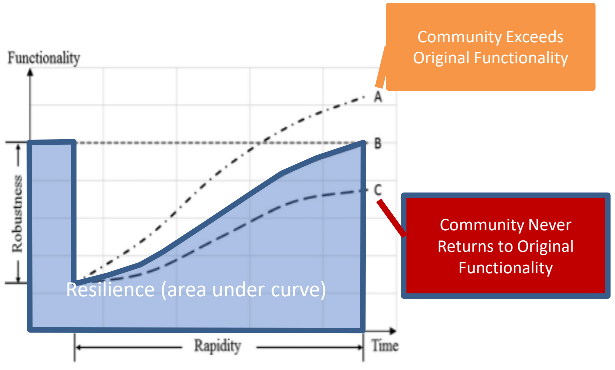


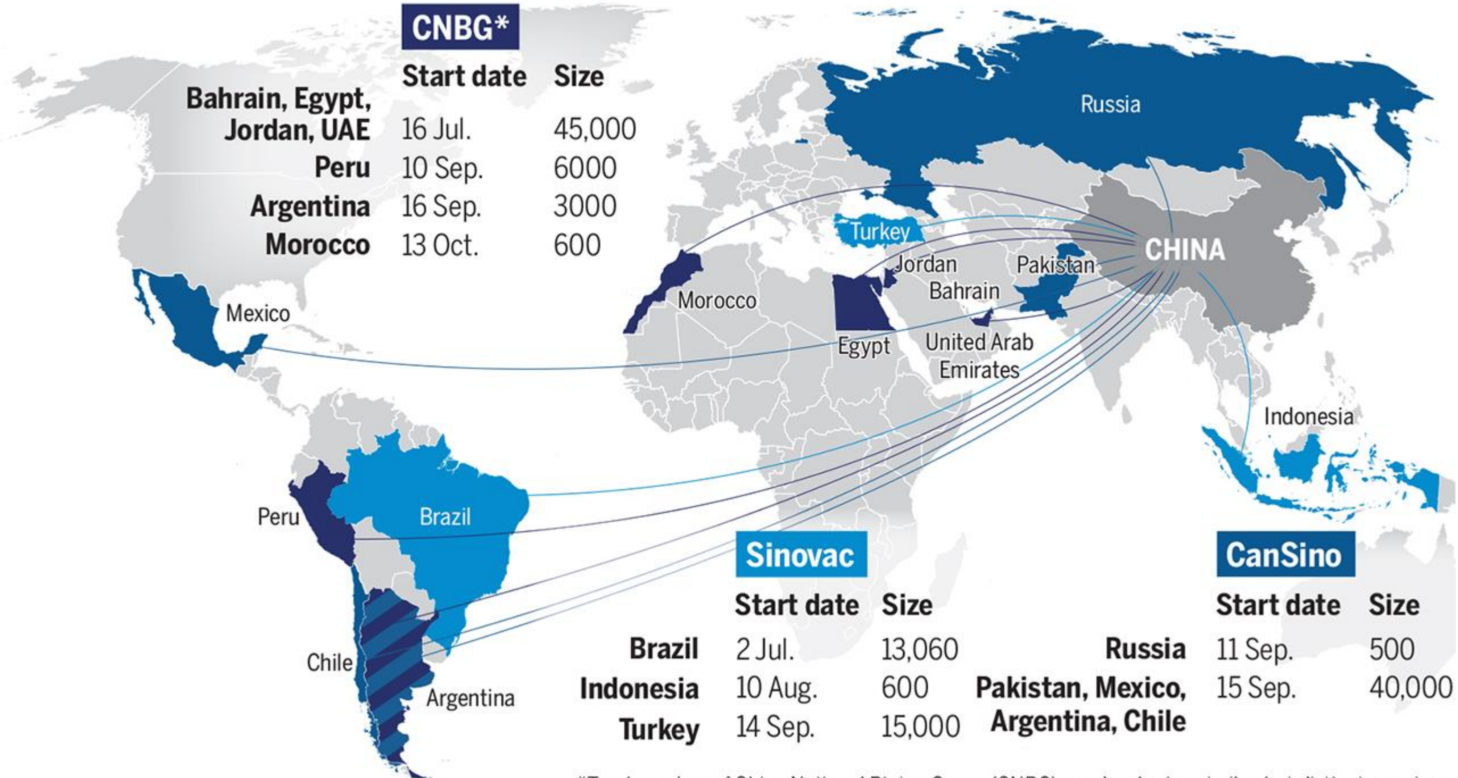
Fig. 1. Resilience-curve model. (Adapted from Cimellaro et al. 2010.)

We can expect some "bounce-back" after mid-2021 after a massive vaccination campaign but not to the pre-COVID-19 baseline

Post-COVID-19 World: A Global Issue

Vaccine road trip

With few COVID-19 cases at home, Chinese vaccinemakers have had to test the worth of their candidates abroad. Four are in efficacy trials in 14 countries.



CNBG*

	Start date	Size
Bahrain, Egypt, Jordan, UAE	16 Jul.	45,000
Peru	10 Sep.	6000
Argentina	16 Sep.	3000
Morocco	13 Oct.	600

Sinovac

	Start date	Size
Brazil	2 Jul.	13,060
Indonesia	10 Aug.	600
Turkey	14 Sep.	15,000

CanSino

	Start date	Size
Russia	11 Sep.	500
Pakistan, Mexico, Argentina, Chile	15 Sep.	40,000

*Two branches of China National Biotec Group (CNBG) are developing similar, but distinct, vaccines.

Cohen, Jon. "China's vaccine gambit." (2020): 1263-1267.

Questions?

Comments?

http://systems.mit.edu