A Summary of Operations Research and Industrial Engineering Tools for Fighting COVID-19

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Outline

- ❑ Overall Lessons
- ❑ Disease Prevention
- ❑ Disease Control During Outbreak
  - Increasing Testing Ability
  - Lockdown and Quarantine
  - Healthcare System Reform and Operations
  - Supply Chains of Essential Items
  - Airline Management and other Related Problems
- ❑ Recovery and Post-Recovery Planning
- ❑ Conclusion

Online Document and Summary

http://www-personal.umich.edu/~siqian/docs/or-ie-fighting-covid19_v1.pdf

From Data to Actions, From Observations to Solutions

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Initial Draft on March 23, 2020
Latest Update on March 24, 2020

Operations Research and Industrial Engineering (OR & IE) approaches are widely used and play important roles in improving the design and operations of many standard corporate activities such as supply chain management, job/staff scheduling, vehicle routing, facility location, and resource allocation. In the midst of the COVID-19 pandemic, policymakers, companies, community workers and individual households have been designing new systems and procedures to fight the virus. Many problems related to optimizing these systems and their operations can be tackled by extending the traditional OR & IE approaches with new objectives, constraints, and input data. The purpose of this document is to **summarize potential scenarios one may encounter during the prevention, disease control, intervention and recovery phases during COVID-19 outbreaks, and point out the OR & IE models that can be applied for solving the related problems**. We are not medical experts and thus will not focus on the drug & vaccine discovery, nor analyzing the disease transmission rate and its spread patterns. Instead, we consider decisions made by multiple stakeholders that can prepare for rare but catastrophic events such as the COVID-19 pandemic, can better inform the public to perform

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Mar 24 · 6 min read

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Acknowledgement

- Current and former IOE PhD students who contributed references and shared ideas.

- PhD students who contributed to making the slides.

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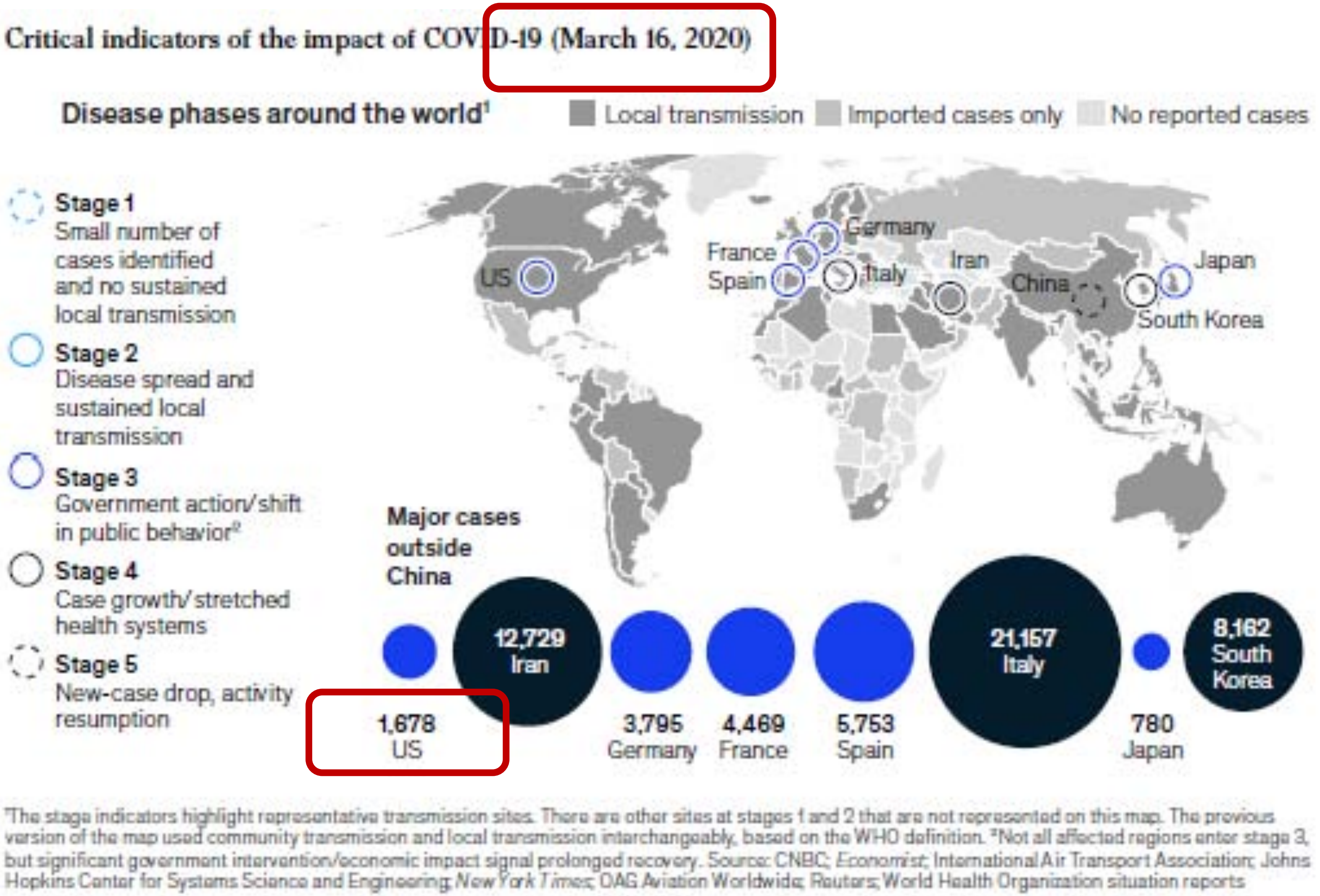
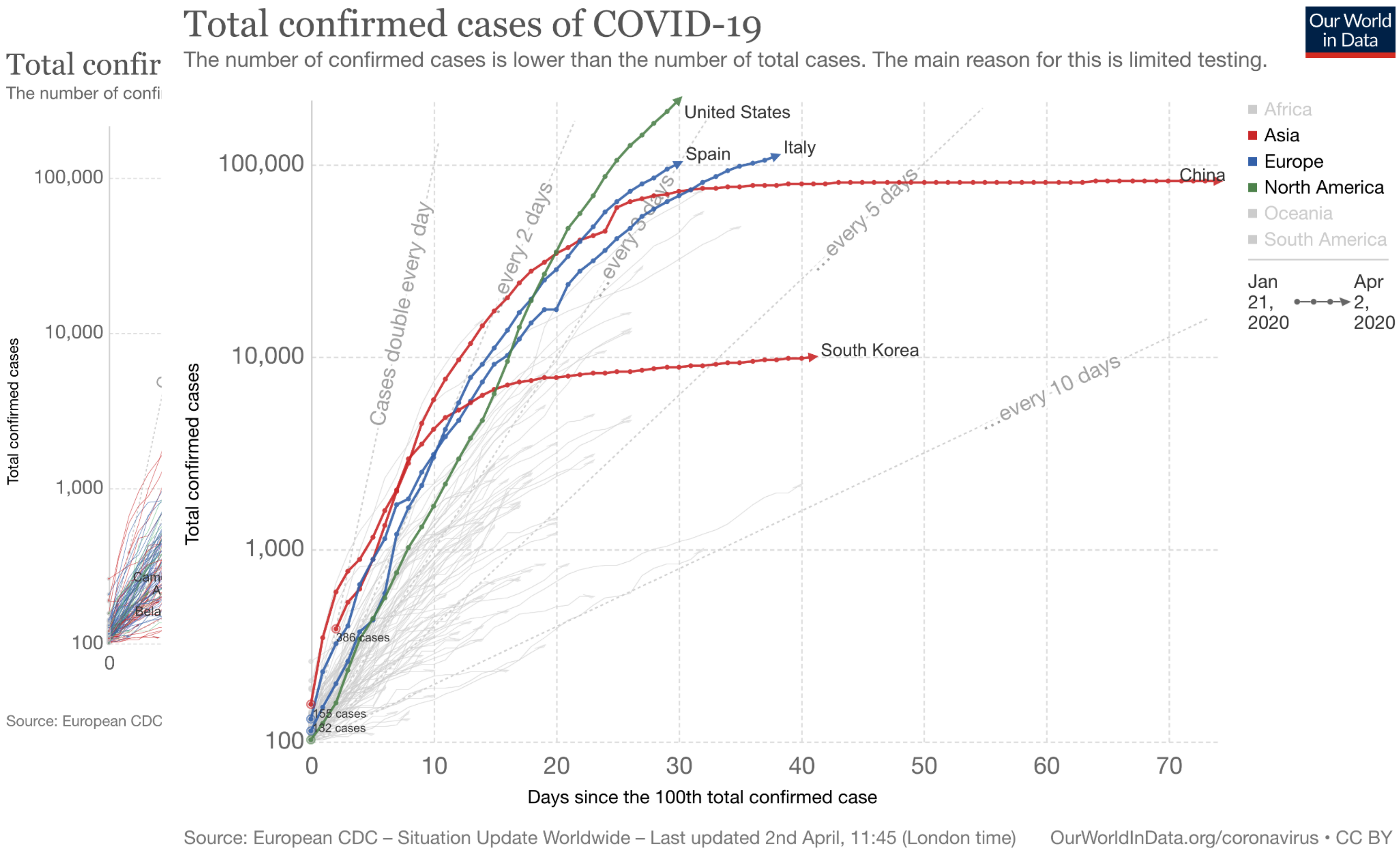
COVID-19 Stages in Different Countries

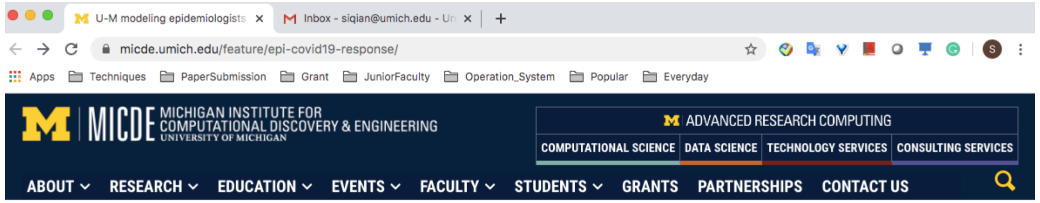


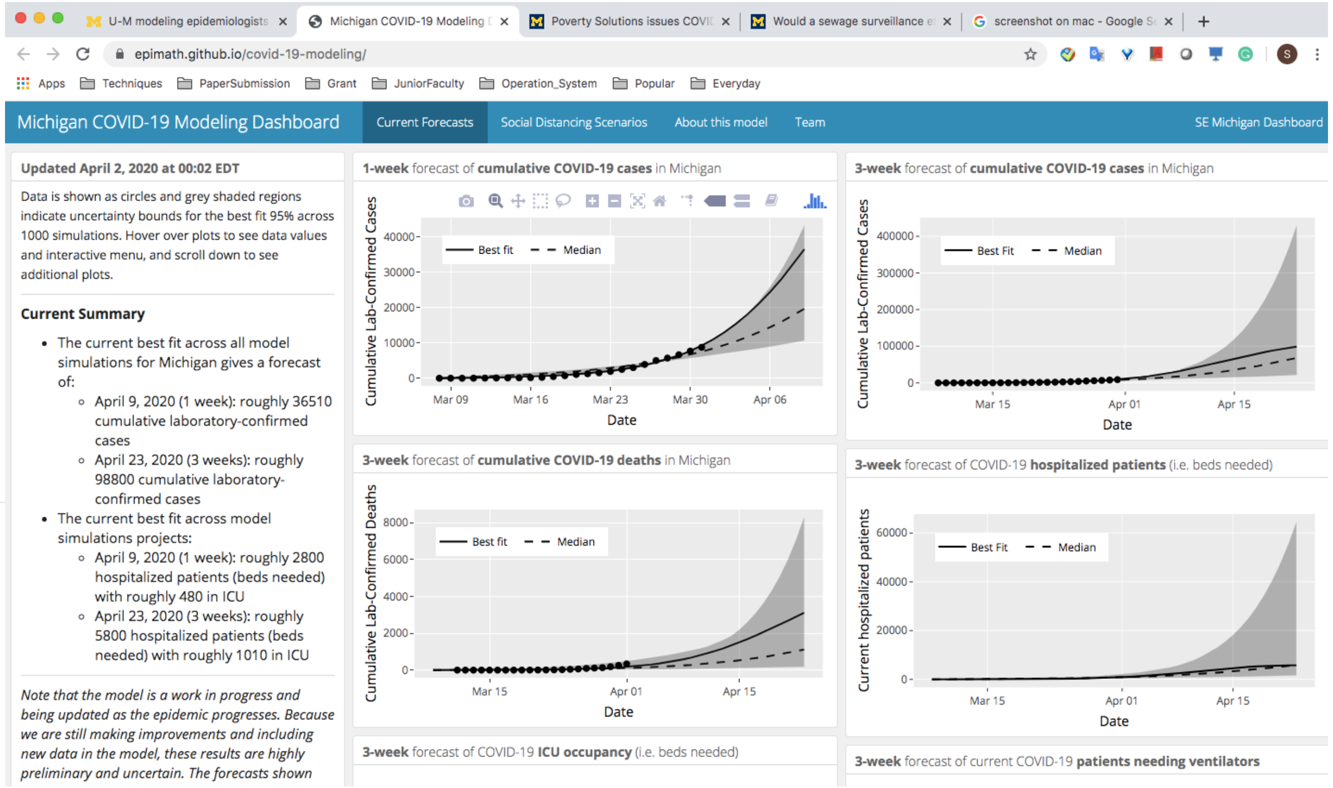
(Source: McKinsey & Company)

What Data Science Can Show Us?



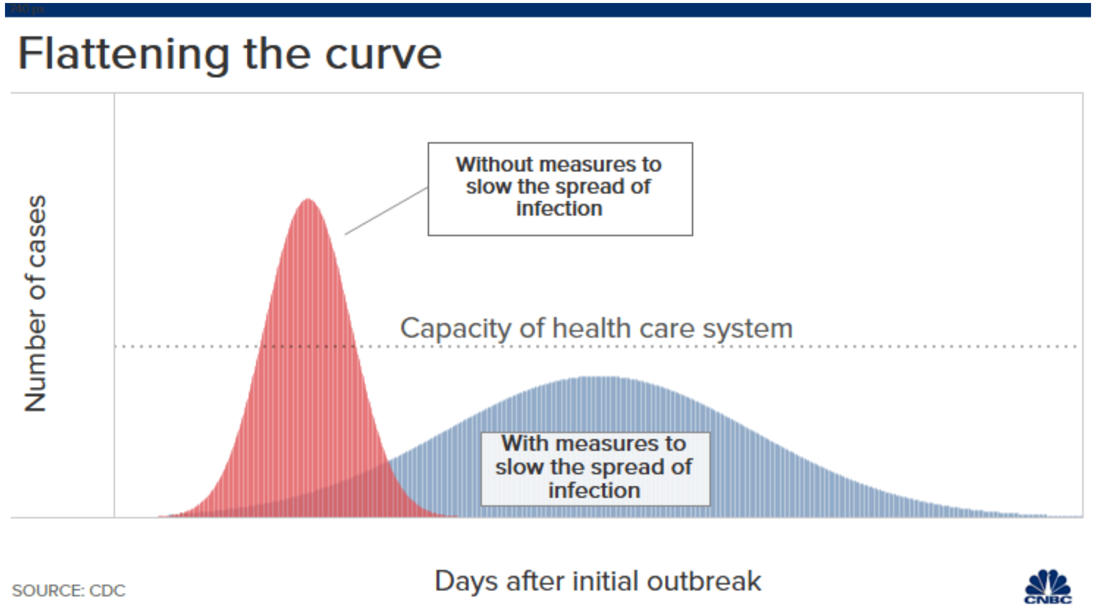
Exponential Growth and Michigan COVID-19 Prediction





From Data to Actions, to Solutions

- What it takes to ``flatten the curve?”
- What problems that are involved in the epidemic **prevention**, **intervention**, **control** and **recovery phases** need to be solved?
- How Operations Research and Industrial Engineering tools can help?



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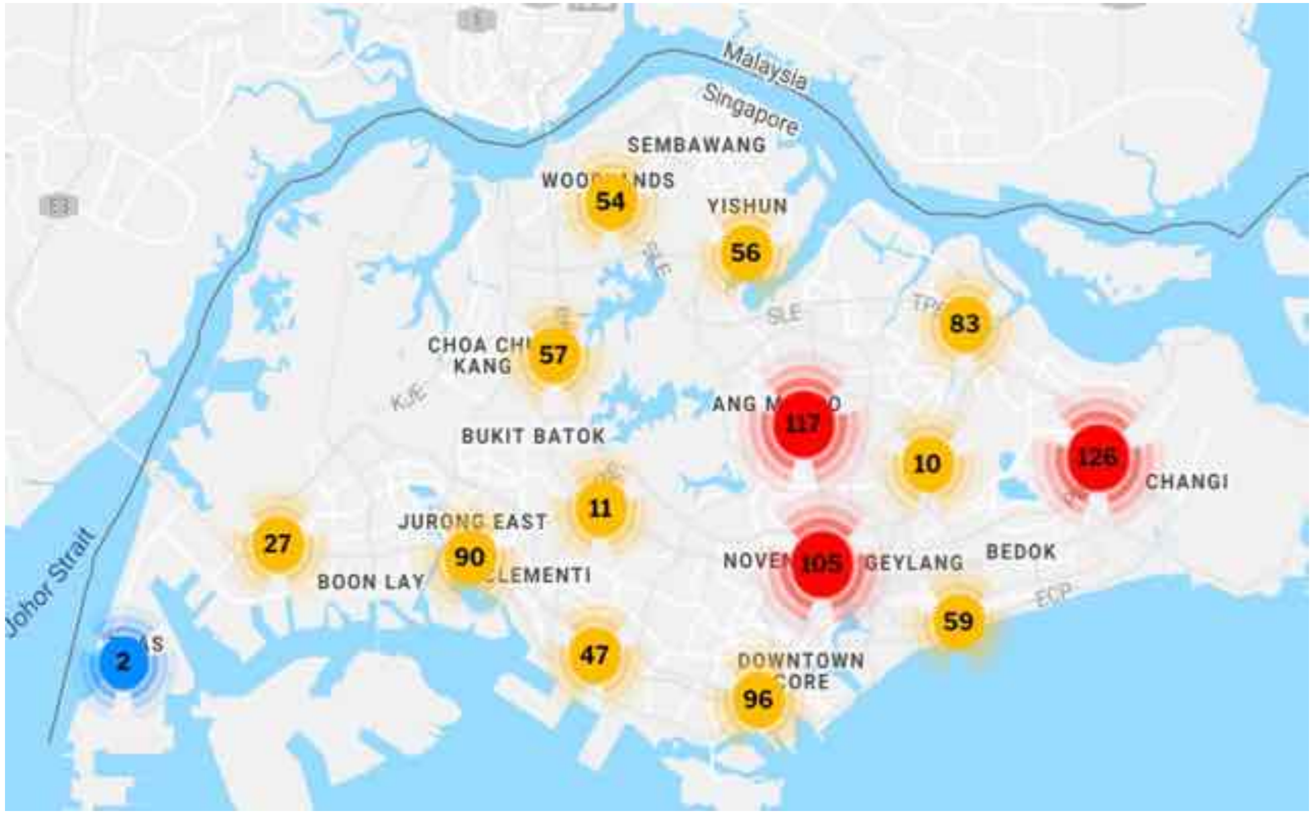
Testing Facility Location Design and Testing Kit Distribution

- **Facility Location Problem (FLP)**
  - Decisions: Where to open facilities
  - Constraints: Satisfy demand and do not exceed production/testing capacity
  - Objective: Minimize cost (e.g., travel convenience, cost for shipping test kits.)

$$\begin{aligned}
\min \quad & \sum_{i=1}^{M} f_i x_i + \sum_{i=1}^{M}\sum_{j=1}^{N} c_{ij} y_{ij} \\
\text{s.t.} \quad & \sum_{i=1}^{M} y_{ij} = d_j, \quad \forall j = 1, \ldots, N, \\
& \sum_{j=1}^{N} y_{ij} \le h_i x_i, \quad \forall i = 1, \ldots, M, \\
& x_i \in \{0,1\}, \quad \forall i = 1, \ldots, M, \\
& y_{ij} \in \mathbb{Z}_+, \quad \forall i = 1, \ldots, M, \; j = 1, \ldots, N.
\end{aligned}$$



A map of Singapore indicating the number of Public Health Preparedness Clinics (PHPCs) in each area. Picture source: https://www.flugowhere.gov.sg/map?HCICode=19M0105&lat=1.36271542&lng=103.854645

To Build A Mathematical Model

- **What we know (Input Data)**
  - Potential # of infected cases and population density, characteristics in each region.
  - Traveling distance from manufactures/individuals to potential testing facilities.
- **What we need to decide (Decision Variables)**
  - Whether or each location (e.g., CVS, Walmart parking lot) will be a potential testing facility.
  - Testing capacities in each location.
  - Shipment volumes between manufactures and potential testing facilities.
- **What are the goals (Objective)**
  - Minimize the total shipment cost from producers to the selected testing facilities.
  - Maximize the traveling convenience from individuals to the selected testing facilities.

Ref: Daskin, M. S. (2011). ***Network and Discrete Location: Models, Algorithms, and Applications.***

What To Learn from Singapore

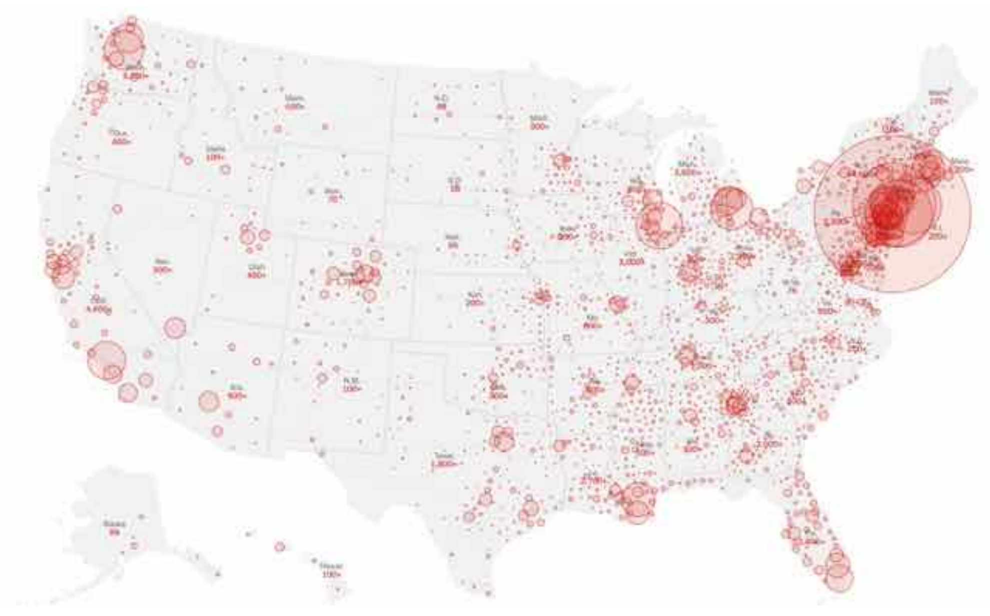
A helpful link to check the PHPC locations in Singapore:
https://www.flugowhere.gov.sg/map?HCICode=19M0105&lat=1.36271542&lng=103.85464

E.g., Ang Mo Kio is an area with many apartments, so there are lots of PHPCs around it.

Locating Key Hospitals and Preparing Enough PPEs

- Facility location with multistage demand uncertainty: We need to consider dynamic demand over time.

$$
\begin{aligned}
\min \quad & \sum_{t=1}^{T}\sum_{i=1}^{M} f_{ti}x_{ti} + \sum_{t=1}^{T}\sum_{i=1}^{M}\sum_{j=1}^{N} c_{tij}y_{tij} \\
\text{s.t.} \quad & \sum_{i=1}^{M} y_{tij} = d_{tj}, \quad \forall j = 1,\ldots,N,\ t = 1,\ldots,T \\
& \sum_{j=1}^{N} y_{tij} \le h_i \sum_{\tau=1}^{t} x_{\tau i}, \quad \forall i = 1,\ldots,M,\ t = 1,\ldots,T \\
& \sum_{\tau=1}^{t} x_{\tau i} \le 1, \quad \forall i = 1,\ldots,M,\ t = 1,\ldots,T \\
& x_{ti} \in \mathbb{Z}_+, \quad \forall i = 1,\ldots,M,\ t = 1,\ldots,T \\
& y_{tij} \in \mathbb{Z}_+, \quad \forall i = 1,\ldots,M,\ j = 1,\ldots,N,\ t = 1,\ldots,T.
\end{aligned}
$$



Picture source: https://www.nytimes.com/interactive/2020/us/coronavirus-us-cases.html?campaignId=7JFJX

Ref: Zaric, G. S., & Brandeau, M. L. (2002). Dynamic resource allocation for epidemic control in multiple populations. *Mathematical Medicine and Biology*, 19(4), 235-255.

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Increasing Testing Ability

South Korea

Health workers in protective suits talk to a motorist at a drive-through testing center for COVID-19 in Seoul. Credit: *Ed Jones/AFP via Getty Images*

Singapore

Singapore has been able to contain the virus, in part by conducting screenings at the airport. Credit: Adam Dean for The New York Times

https://www.nytimes.com/2020/03/20/world/europe/coronavirus-testing-world-countries-cities-states.html

Increasing Testing => Early Detection and Treatment

THE CORONAVIRUS CRISIS

How South Korea Reined In The Outbreak Without Shutting Everything Down

March 26, 2020 · 2:41 PM ET

JASON BEAUBIEN

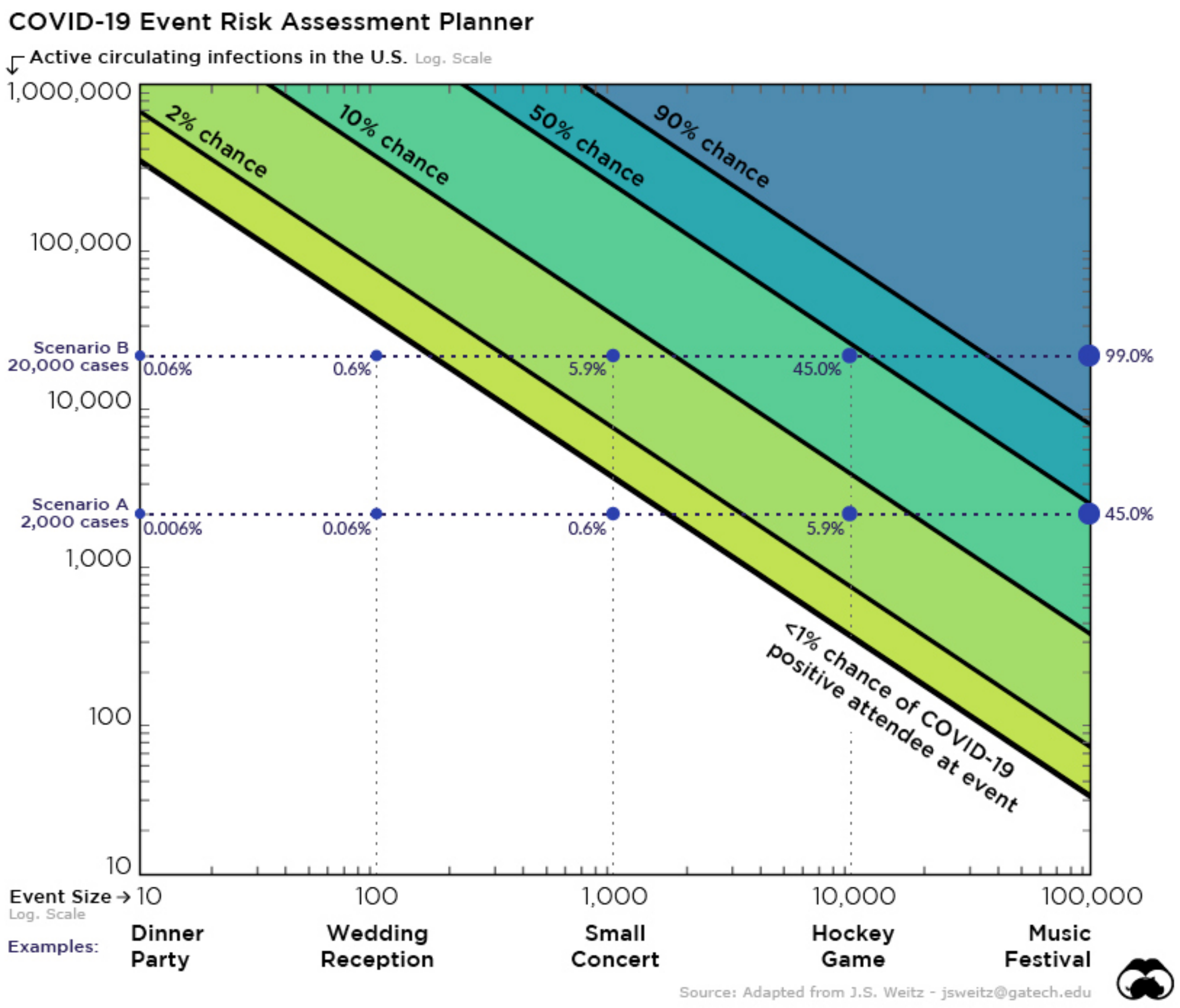
- “countries that have tested widely for the virus, isolated cases and quarantined suspected cases — in the way that South Korea and Singapore have done — have managed to suppress transmission of the virus”

- “the key lessons from her country are that it developed testing for the virus even before it had a significant number of cases”

- "**Testing is central to the outbreak response”**, said Kang, "because that leads to **early detection**. It minimizes further spread." And it allows health authorities to quickly isolate and treat those found with the virus.

https://www.npr.org/sections/goatsandsoda/2020/03/26/821688981/how-south-korea-reigned-in-the-outbreak-without-shutting-everything-down

When and How to Lockdown



Depending on different severity levels of virus spread, medical supply shortage, and prediction of future situation, policy makers need to dynamically decide what types of events, stores, restaurants, and other public facilities to close, whether we close schools, parks, etc.

Prevention vs. Intervention

Eerie scenes of an empty New York City as coronavirus lockdown looms
Credit: Daniel William McKnight for The New York Post

https://nypost.com/2020/03/21/eerie-scenes-of-an-empty-new-york-city-as-coronavirus-lockdown-looms/

"By the time you detect the virus in someone, it was something they caught about a week prior, so the spreading is a week old. You have to do something that prevents infections next week, not last week. We tried to do something to prevent spreading without going too extreme. This is not something that will go away quickly. It's not a sprint, it's a marathon. The trick too is to detect cases early on because it is harder to contain a big numbers of cases."

— Vernon Lee, Director of Communicable Diseases, Ministry of Public Health, Singapore.

To Build A Lockdown Model

- **What we know (Input Data)**
  - The frequency that each location/facility is visited and how important they are to people's daily life
- **What we need to decide (Decision Variables)**
  - Whether or not to close each facility (if yes, then at what time)
- **What are the goals (Objective)**
  - Minimize the total infections while supporting people's daily-life needs
  - Minimize the inconvenience caused by facility locked-down
  - Minimize economic impact
  - …

Lockdown – A Knapsack Problem

- Select facilities to close and populations to quarantine/get vaccination

$$\text{DPEC-B}: \quad \min_{x,z} \quad \sum_{j\in\mathcal{F}} \rho_j \left(\sum_{i\in\mathcal{P}} p_{ij}(1-h_i)\left(r_i^{AV} z_i + r_i^{BV}(1-z_i)\right) \right)(1-x_j) \tag{2a}$$

$$\text{s.t.} \quad \sum_{i\in\mathcal{P}} c_i z_i \leqslant B_z \tag{2b}$$

$$\sum\nolimits_{j\in\mathcal{F}} d_j x_j \leqslant B_x \tag{2c}$$

$$x_j \in \{0,1\} \quad \forall j \in \mathcal{F} \qquad z_i \in \{0,1\} \quad \forall i \in \mathcal{P}. \tag{2d}$$

- Such a static model can be extended to a dynamic setting if we update the virus spread information periodically and make updated lockdown decisions sequentially.

Ref: Deng, Y., Shen, S., & Vorobeychik, Y. (2013). Optimization methods for decision making in disease prevention and epidemic control. Mathematical Biosciences, 246(1), 213-227.

To Build A Quarantine Model

- **What we know (Input Data)**

  A network with nodes representing population groups or facilities and edges representing how they are connected.

- **What we need to decide (Decisions)**
  - Identify the most critical nodes (e.g., facilities visited by most people daily or workers such as doctors who may infect a large number of vulnerable populations if they are sick)
- **What are the goals (Objective)**
  - Provide extra protection for the most critical nodes during their normal operations or quarantine them if they are infected

An Interdiction Model for Disconnecting a Network

- Decide which node(s) to delete (quarantine) to maximize network disconnectivity.

$$\max \ \eta(x, y) - \frac{1}{n} \sum_{i \in \mathcal{V}} (1 - x_i)$$

$$\text{s.t.} \ \sum_{i \in \mathcal{V}} (1 - x_i) \leq B$$

$$x_i + x_j - 1 \leq y_{ij}, \quad y_{ij} \leq x_i, \ y_{ij} \leq x_j \ \forall (i, j) \in \mathcal{E}$$

$$x_i \in \{0, 1\} \quad \forall i \in \mathcal{V}$$

$$0 \leq y_{ij} \leq 1 \quad \forall (i, j) \in \mathcal{E}.$$

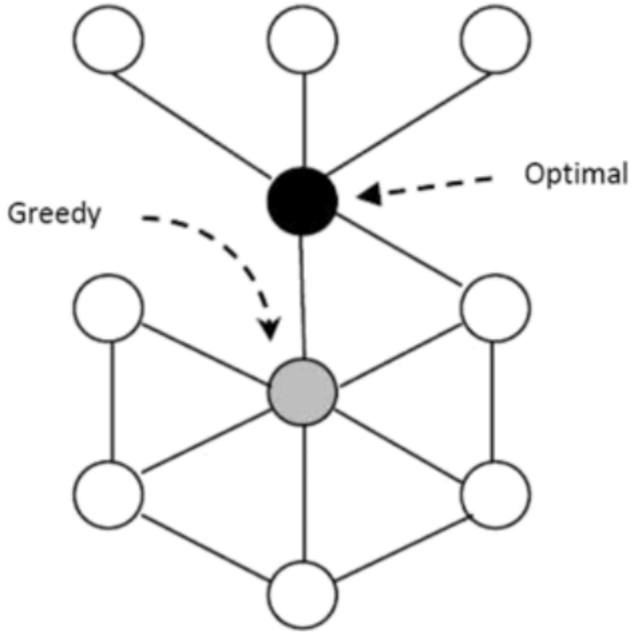


Fig. 1. Suboptimality of the greedy algorithm in MaxNum for $B = 1$.

Ref: Shen, S., Smith, J. C., & Goli, R. (2012). Exact interdiction models and algorithms for disconnecting networks via node deletions. Discrete Optimization, 9(3), 172-188.

To Build A Treatment Model

- **What we know (Input Data)**
  - A network with nodes and edges to model social connections and interactions
  - The number of agents that move and clean a spreading contamination
  - Contamination/cleaning speed
- **What we need to decide (Decisions)**
  - Select nodes to “clean” (treat) when the virus moves around to infect non-quarantined nodes.
- **What are the goals (Objective)**
  - Minimize the time to decontaminate the graph
  - Minimize the number of cleaning agents needed

Integer Programming for Configuring Treatment Plans

- Finding the fastest cleaning strategy while the virus is spreading:

$$Q^{\mathbf{c}}_{\mathcal{L}}(x) = \min \sum_{t=0}^{t_{\max}} y^t \tag{1a}$$

$$\text{s.t. } v^0_\ell \geq 1 - x_\ell \quad \forall \ell \in \mathcal{L} \tag{1b}$$

$$u^0_i \leq x_i \quad \forall i \in V \tag{1c}$$

$$u^t_i \leq \sum_{h \in N[i]} u^{t-1}_h \quad \forall i \in V,\ t = 1, \ldots, t_{\max} \tag{1d}$$

$$v^t_i \geq v^{t-1}_j - u^t_i \quad \forall i \in V,\ j \in N[i],\ t = 1, \ldots, t_{\max} \tag{1e}$$

$$y^t \geq v^t_i \quad \forall i \in V,\ t = 0, \ldots, t_{\max} \tag{1f}$$

$$v^t_i \geq 0 \quad \forall i \in V,\ t = 0, \ldots, t_{\max} \tag{1g}$$

$$0 \leq u^t_i \leq 1 \quad \forall i \in V,\ t = 0, \ldots, t_{\max}. \tag{1h}$$

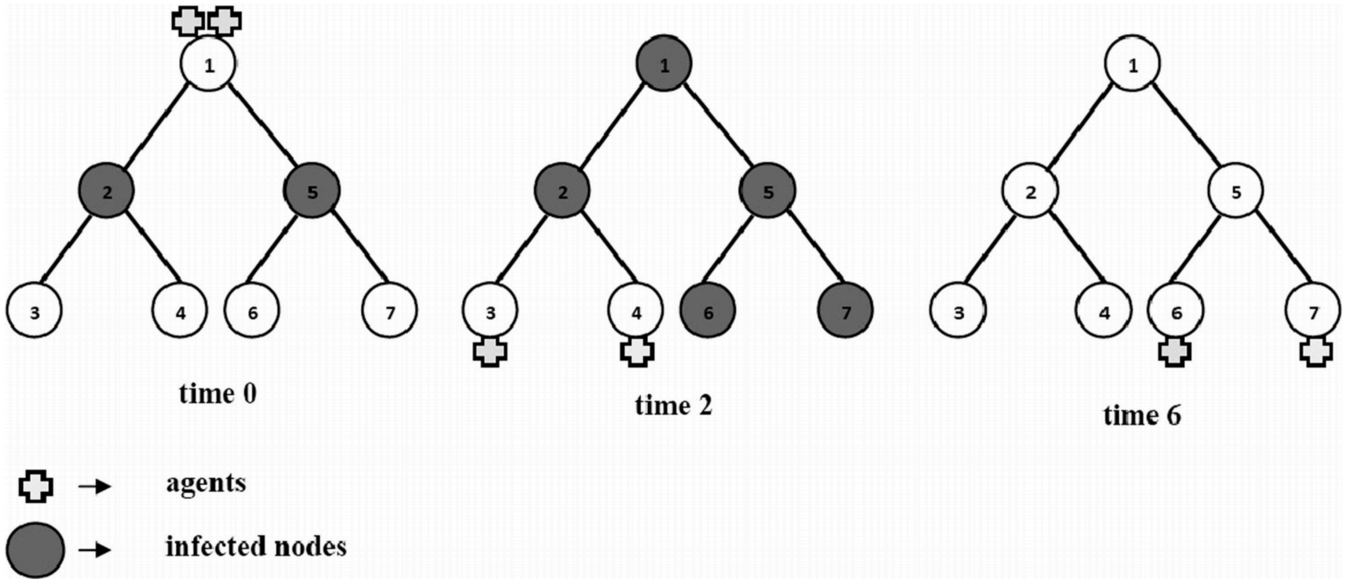


FIG. 1. Illustration of passing and nonmonotone contamination.

Ref: Penuel, J., Cole Smith, J., & Shen, S. (2013). Integer programming models and algorithms for the graph decontamination problem with mobile agents. Networks, 61(1), 1-19.

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Improving Healthcare Operations

Issue: High demand under tight resources

Goal: Avoid overcrowdedness and cross-infection

ICU bed allocation

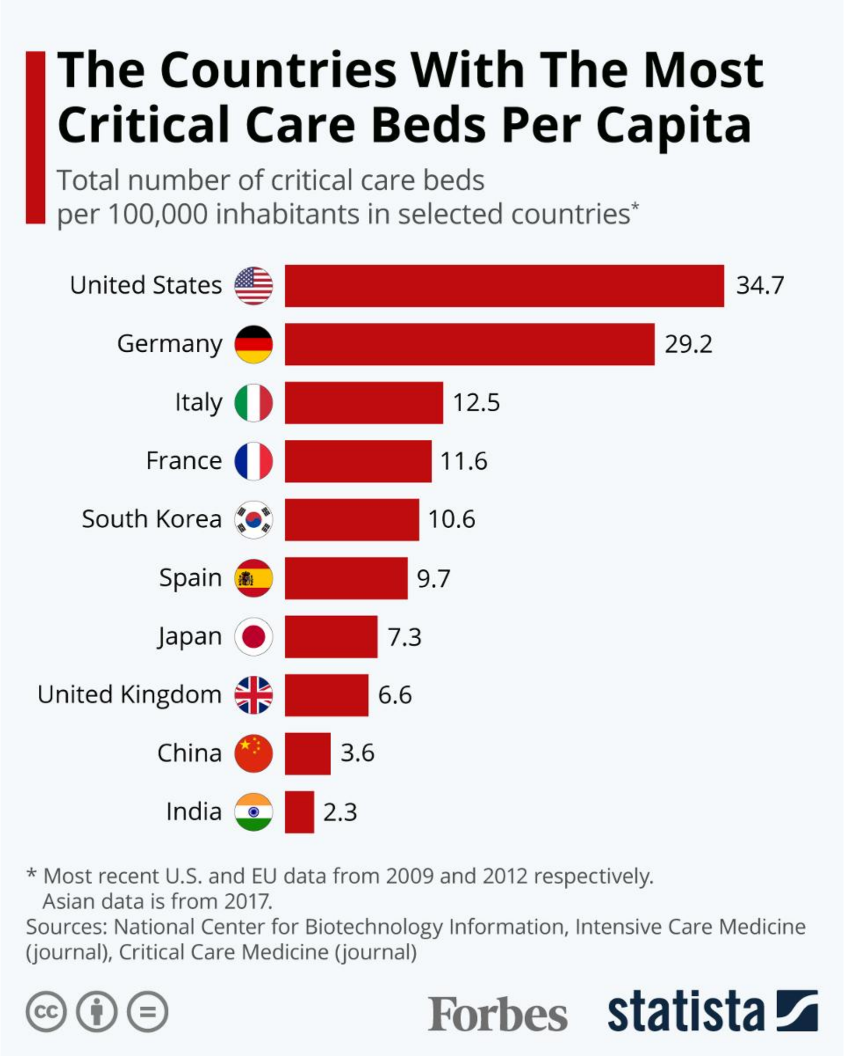
Staff planning

Patient admission Control

Ambulance dispatch

https://www.americamagazine.org/politics-society/2020/03/27/what-its-be-hospital-chaplain-during-covid-19
https://www.reuters.com/article/us-health-coronaviru-usa-emts/coronavirus-outbreak-is-stretching-new-yorks-ambulance-service-to-breaking-point-idUSKBN21F0HF
http://theconversation.com/who-needs-to-be-in-an-icu-its-hard-for-doctors-to-tell-56728
https://www.wsj.com/articles/if-we-fail-what-happens-to-you-all-one-doctors-life-on-the-coronavirus-front-lines-11583344415

Is US Fine with ICU Beds?



What is NOT reflected in the figure:

- Imbalanced healthcare resources in different states, counties in the US.
- Extremely high population density in certain regions, e.g., NYC.
- Normal ICU bed demand and utilization.
- Extremely high healthcare cost and ICU cost in the US.

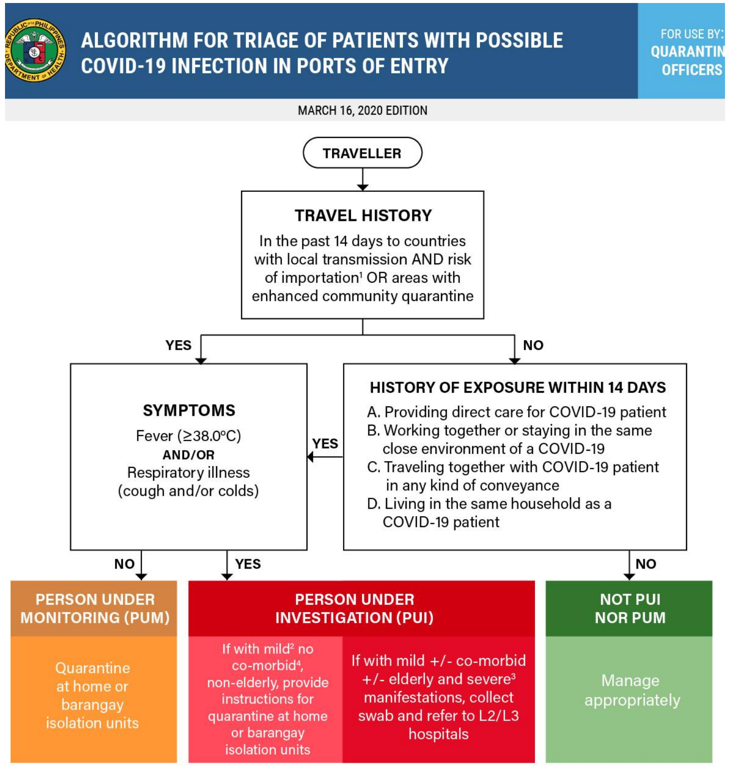
Patient Triage and Admission Control

What we need to decide:

- Prioritize which patients need to be tested & admitted
- How to triage patient flows in emergency departments
- Assign appropriate shifts to doctors and nurses

What we consider:

- Patient safety
- Operational efficiency
- The risk that healthcare providers are exposed to infectious patients



Department of Health published algorithm for triage of patients with possible COVID-19 infection.

PRIORITY 1
Ensure optimal care options for all hospitalized patients, lessen the risk of nosocomial infections, and maintain the integrity of the healthcare system

- Hospitalized patients
- Symptomatic healthcare workers

PRIORITY 2
Ensure that those who are at highest risk of complication of infection are rapidly identified and appropriately triaged

- Patients in long-term care facilities with symptoms
- Patients 65 years of age and older with symptoms
- Patients with underlying conditions with symptoms
- First responders with symptoms

PRIORITY 3
As resources allow, test individuals in the surrounding community of rapidly increasing hospital cases to decrease community spread, and ensure health of essential workers

- Critical infrastructure workers with symptoms
- Individuals who do not meet any of the above categories with symptoms
- Health care workers and first responders
- Individuals with mild symptoms in communities experiencing high COVID-19 hospitalizations

CDC updated the priority list for evaluation and laboratory testing for COVID-19.

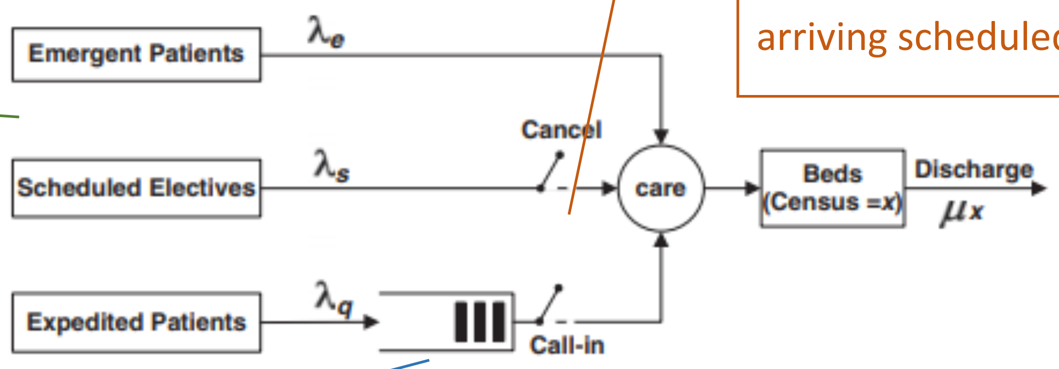
https://www.cdc.gov/coronavirus/2019-nCoV/hcp/clinical-criteria.html https://twitter.com/PhilippineStar/status/1239398853888995328

Patient Triage and Admission Control

Prioritize which patients need to be tested & admitted

- An expedited patient care queue (a Markov decision process model)
- To strike a balance between bed utilization and hospital congestion

Scheduled patients and emergency patients are assigned hospital beds according to a Poisson process .



The controller has the option of canceling an arriving scheduled patient

Call-in patients are placed on the call-in queue according to a Poisson process and are then assigned a hospital bed (admitted) via the admission controller’s call-in action.

Ref: Helm, J. E., AhmadBeygi, S., & Van Oyen, M. P. (2011). Design and analysis of hospital admission control for operational effectiveness. Production and Operations Management, 20(3), 359-374.

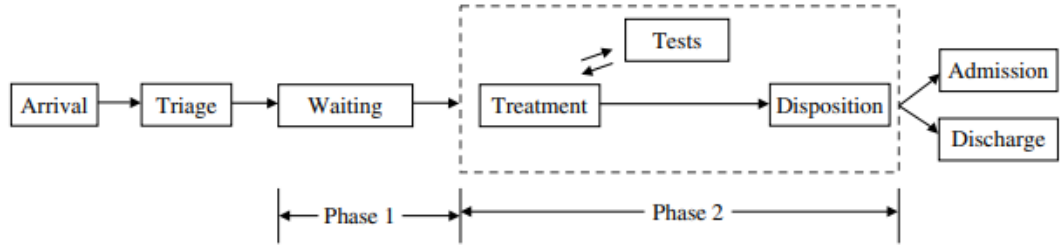
Patient Triage and Admission Control

Triage patient flows in emergency departments

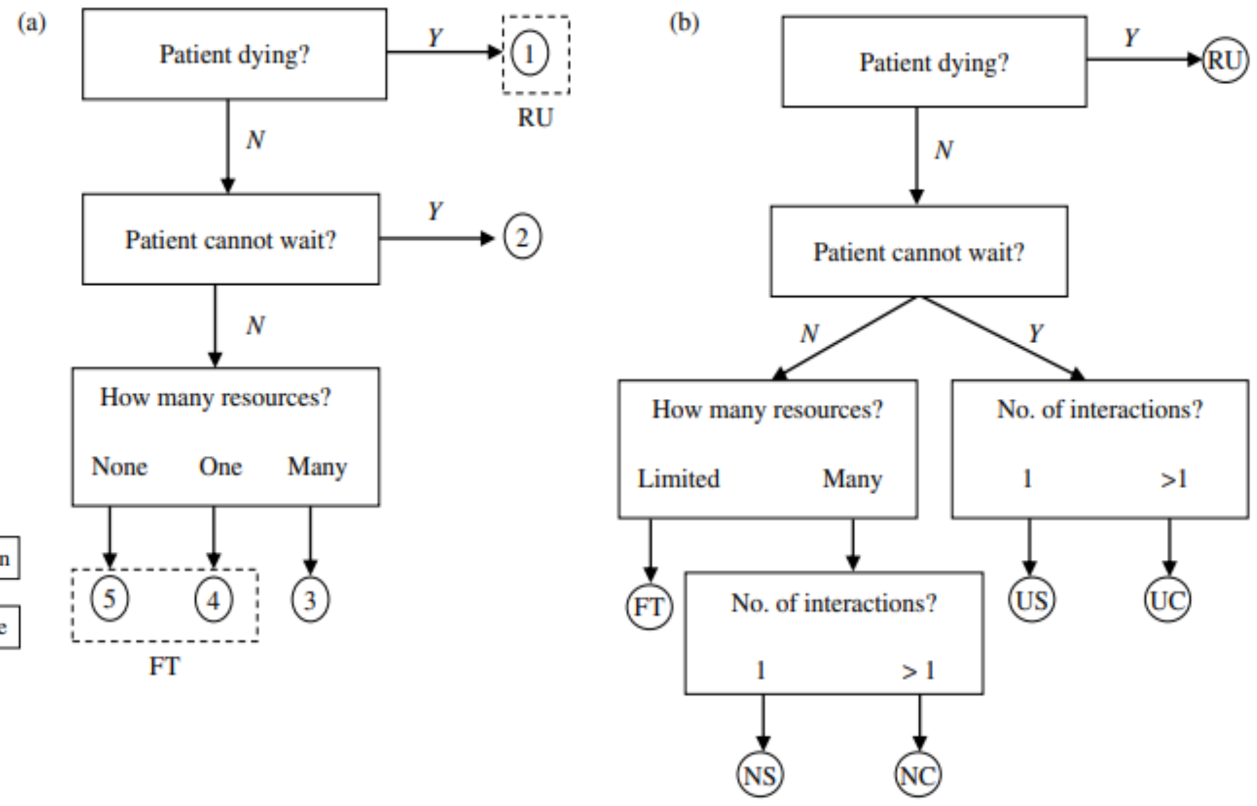
Two challenges:

1. Deciding what information to collect at triage
2. Determining how to use the information to improve performance.
    - Separate patients into streams and prioritize them within the streams.

General Flow of Patients in the Main ED



(a) Typical Five-Level Triage System (see, e.g., Gilboy et al. 2005); (b) Proposed Complexity-Augmented Triage System



Note. RU, resuscitation unit; FT, fast track; NS, nonurgent simple; NC, nonurgent complex; US, urgent simple; UC, urgent complex.

Ref: Saghafian, S., Hopp, W. J., Van Oyen, M. P., Desmond, J. S., & Kronick, S. L. (2014). Complexity-augmented triage: A tool for improving patient safety and operational efficiency. Manufacturing & Service Operations Management, 16(3), 329-345.

Hospital Capacity Allocation

CNN US

Inside a Brooklyn hospital that is overwhelmed with Covid-19 patients and deaths


By Miguel Marquez and Sonia Moghe, CNN

Updated 12:25 PM ET, Mon March 30, 2020

The ICU is at capacity, patient beds line the hallways of the emergency department, and the morgue is overflowing.

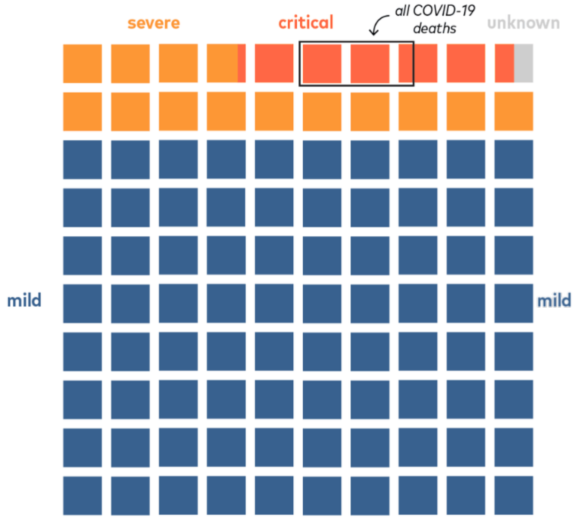
Plastic sheets separate an area of the hospital being used to treat coronavirus patients.

https://www.cnn.com/2020/03/30/us/brooklyn-hospital-coronavirus-patients-deaths/index.html

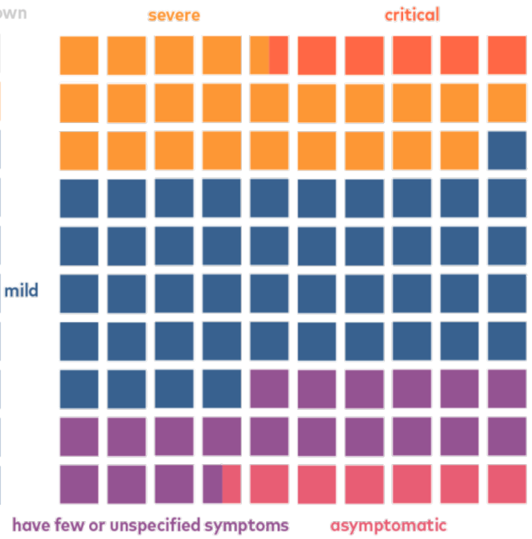
Importance of ICU Beds Allocation

Having enough ICUs and ventilators is critical for treating COVID-19 patients as about 20% patients reported so far have critical conditions.

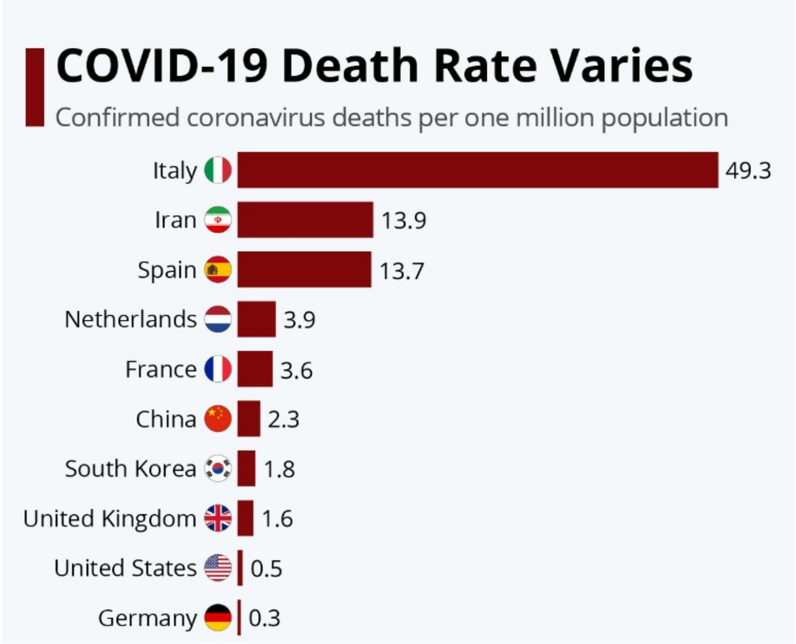
As an example, as of March 23, 2020, Germany has 132 deaths among all the 31,370 confirmed cases, close to 0.4% fatality rate, as compared to the nearly 10% fatality rate in Italy.



China



Italy



https://www.statista.com/chart/21170/coronavirus-death-rate-worldwide/
https://www.forbes.com/sites/niallmccarthy/2020/03/12/the-countries-with-the-most-critical-care-beds-per-capita-infographic/#36994f817f

Ways to Expand Capacities

Create plans to increase capacity

Converting single rooms to doubles

Discharging patients

Reducing admissions for non-COVID-19 care

Defining how to allocate scarce technologies (involving clinical staff and ethicists)

Providing training to healthcare workers

https://labblog.uofmhealth.org/industry-dx/what-can-hospitals-do-to-prepare-for-covid-19-cases https://www.wsj.com/articles/new-york-mandates-nursing-homes-take-covid-19-patients-discharged-from-hospitals-11585228215 https://blog.petrieflom.law.harvard.edu/2020/03/02/controlling-the-novel-coronavirus-should-we-have-stopped-the-covid-19-coronavirus-more-effectively-could-we-still/ https://www.statnews.com/2020/03/17/allocate-ventilators-other-covid-19-resources-based-on-evidence/ https://thehill.com/opinion/healthcare/490034-how-hospitals-will-decide-who-lives-and-who-dies-in-our-coronavirus-crisis

To Build A Mathematical Model

Condition:

- Patients are divided into different types. The wards for each patient type are separated.

What we know (Input Data):

- Patients transition from one type to another.
- Each medical staff has their specialties and working-shift preferences.

What we need to decide (Decision Variables):

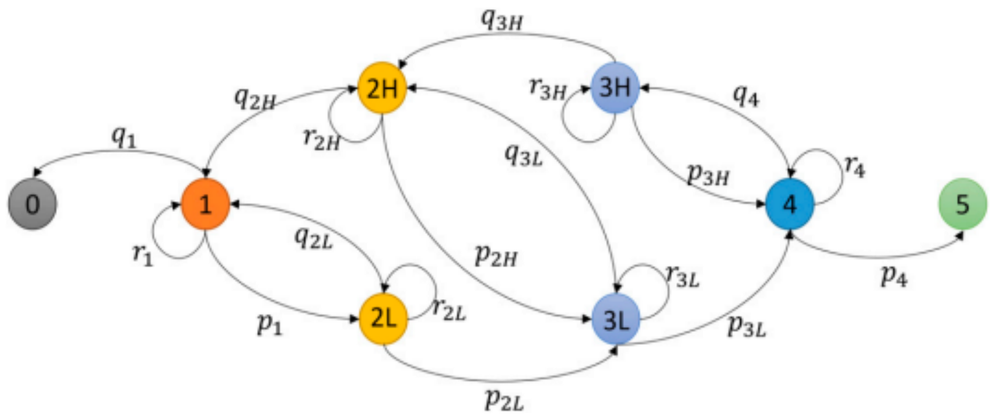
- How to allocate capacity (i.e., number of beds and medical staff) in each ward.

Allocation of ICU beds (Modeled as a Markov Decision Processes (MDP))

1. Whether the patient should be admitted to the ICU or the general ward?
2. Which patients in the ICU (if any) should be early discharged to the general ward?

Goal: minimize death troll

Figure 2. (Color online) Transition Diagram for Patient Evolution in the ICU



Ref: Ouyang, H., Argon, N. T., & Ziya, S. (2020). Allocation of intensive care unit beds in periods of high demand. Operations Research. (https://doi.org/10.1287/opre.2019.1876)

Dispatching Ambulances

Paramedics gather as they prepare ambulances to transport patients infected with the COVID-19 coronavirus in Daegu, South Korea

A view of parked ambulances in front of NYU Langone hospital amid the coronavirus (COVID-19) outbreak on March 26, 2020 in New York City.

https://www.bangkokpost.com/world/1869164/s-korea-wages-all-out-responses-to-virus-with-586-new-cases
https://www.cnbc.com/2020/03/28/new-york-city-hospital-criticized-for-slow-coronavirus-protections.html

A Mixed-Integer Programming Model

$$\max_x \sum_{i\in I}\sum_{j\in J}\sum_{k=1}^{s}\left(c_{ijk}^H x_{ijk}^H + w c_{ijk}^L x_{ijk}^L\right) \quad (19)$$ → weighted expected coverage over high and low priority calls.

subject to

$$\sum_{i\in I} y_i = s, \quad (20)$$ → open stations

$$\sum_{k=1}^{s} x_{ijk}^p = y_i, \quad \forall i \in I, j \in J, p \in \{H, L\}, \quad (21)$$ → available ambulances

$$\sum_{i\in I} x_{ijk}^p = 1, \quad \forall j \in J, k = 1, \cdots, s, p \in \{H, L\}, \quad (22)$$ → prioritize ambulances for each call

$$\sum_{j\in J}\sum_{k=1}^{s}\sum_{p\in\{H,L\}} \lambda_j^p q_{k-1}^p (1-r) r^{k-1} \tau_{ij} x_{ijk}^p \le (r+\delta) y_i, \quad \forall i \in I, \quad (23)$$

$$\sum_{j\in J}\sum_{k=1}^{s}\sum_{p\in\{H,L\}} \lambda_j^p q_{k-1}^p (1-r) r^{k-1} \tau_{ij} x_{ijk}^p \ge (r-\delta) y_i, \quad \forall i \in I, \quad (24)$$

(23)–(24): load balancing constraints

$$x_{ij'1}^H \ge x_{ij1}^H, \quad j \in J, i \in I, j' \in N_{ij}, \quad (25)$$

$$y_i \in \{0, 1\}, \quad i \in I, \quad (26)$$

$$x_{ijk}^p \in \{0, 1\}, \quad i \in I, j \in J, k = 1, \cdots, s, p \in \{H, L\}. \quad (27)$$

Ref: Yoon, S., Albert, L. 2018. An Expected Coverage Model with a Cutoff Priority Queue. Health Care Management Science, 21(4), 517 – 533.

Telemedicine Service Scheduling

Telehealth Offers a Lifeline for Cardiology Patients During the COVID-19 Pandemic.

#	Medical Institutions' Names	URL, Wechat Official Account	
1	Dingxiang Doctor	Wechat Official Account: DingXiangYiSheng	Prevention o
2	Tongji Hospital of Huazhong University of Science and Technology	Wechat Official Account: whtongji1900	click on the l on "发热门诊 patients (phc
3	Xuzhou Healthy Link Combined Micropulse	click here to visit	Free online c
4	We Doctor	www.guahao.com	Free consulta
5	Haodaifu Online	https://www.haodf.com/jibing/feiyan.htm	Fees unknow
6	Nanjing Drum Tower Hospital	Official Wechat Official Account: njglyy1892. Follow the official account first, click the button on the right "患者服务(service for patients)"then go to "互联网医院(online hospital)". Click the right button"我的(my account)"to register and sign up your own account before you go to"图文/视频咨询(picture and video consultation)", button on the left"发热筛查门诊(fever outpatients self-check)".	online fever c

A summary of online doctors in China.

TYPE OF SERVICE	WHAT IS THE SERVICE?	HCPCS/CPT CODE	Patient Relationship with Provider
MEDICARE TELEHEALTH VISITS	A visit with a provider that uses telecommunication systems between a provider and a patient.	Common telehealth services include: • 99201-99215 (Office or other outpatient visits) • G0425–G0427 (Telehealth consultations, emergency department or initial inpatient) • G0406–G0408 (Follow-up inpatient telehealth consultations furnished to beneficiaries in hospitals or SNFs) For a complete list: https://www.cms.gov/Medicare/Medicare-General-Information/Telehealth/Telehealth-Codes	For new* or established patients. *To the extent the 1135 waiver requires an established relationship, HHS will not conduct audits to ensure that such a prior relationship existed for claims submitted during this public health emergency
VIRTUAL CHECK-IN	A brief (5-10 minutes) check in with your practitioner via telephone or other telecommunications device to decide whether an office visit or other service is needed. A remote evaluation of recorded video and/or images submitted by an established patient.	• HCPCS code G2012 • HCPCS code G2010	For established patients.
E-VISITS	A communication between a patient and their provider through an online patient portal.	• 99431 • 99422 • 99423 • G2061 • G2062 • G2063	For established patients.

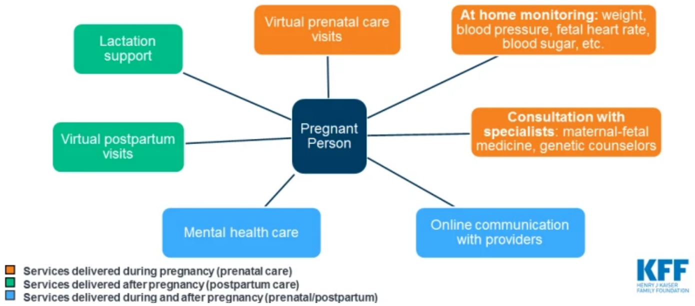
Three main types of virtual services physician.

Telehealth During COVID-19: How Hospitals, Healthcare Providers Are Optimizing Virtual Care

Matthew Gavidia

> Amid the COVID-19 pandemic, patients, as well as their physicians, have been put at risk while seeking or providing other healthcare. While several barriers to care have inhibited telehealth in the past, recent actions by CMS, HHS, and other governing bodies have sought to expand its availability nationwide. NYU Langone Health's telehealth service Virtual Urgent Care connects members with clinicians via phone or tablet to provide care without potential coronavirus exposure.

During The COVID-19 Pandemic, Many Pregnancy-Related Services Could Be Delivered Via Telemedicine



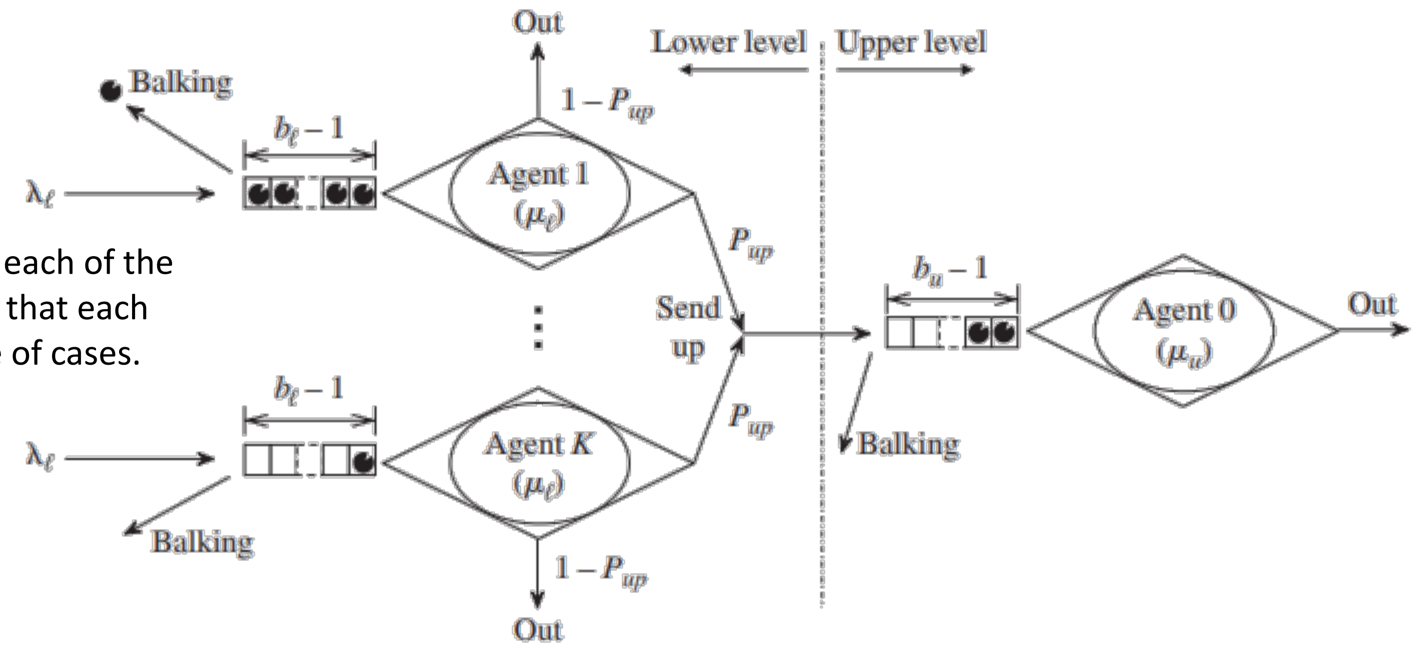
https://github.com/Support-WuHan/Online-Doctors-Info/blob/master/README-en.md https://www.tctmd.com/news/telehealth-offers-lifeline-cardiology-patients-during-covid-19-pandemic https://www.aafp.org/dam/AAFP/documents/advocacy/prevention/crisis/CMSGeneralTelemedicineToolkit.pdf https://www.kff.org/womens-health-policy/issue-brief/novel-coronavirus-covid-19-special-considerations-for-pregnant-women/ https://www.ajmc.com/focus-of-the-week/telehealth-during-covid19-how-hospitals-healthcare-providers-are-optimizing-virtual-care

Hierarchical Knowledge Based Service Systems

- **A two-level system** (cases are needed to be confirmed as urgent or not)
  1. first assessed at the lower level (e.g., triage nurses)
  2. then sent to the upper-level agent (e.g., the telemedical physician (TP)) if needed.
- **Goal:** minimize decision error

Modeling Network Flows in a Two-Level Knowledge-Based Service System

We assume that cases arrive at each of the lower level agents at rate λ_l, so that each agent has his or her own queue of cases.



Ref: Saghafian, S., Hopp, W. J., Iravani, S. M., Cheng, Y., & Diermeier, D. (2018). Workload management in telemedical physician triage and other knowledge-based service systems. Management Science, 64(11), 5180-5197

Medical Home Care (MHC)

MHC delivers certified nurses and supplies to patient homes

- Provide services to self-quarantine patients
- Serve **elder patients** with **chronic disease** to avoid cross-infection
- Alleviate stress on the medical systems

Modern Healthcare

LATEST NEWS | INSIGHTS | TRANSFORMATION | DATA/LISTS | OP-ED | AWARDS | EVENTS

Home › Home Health

March 18, 2020 08:58 PM

Home healthcare looks to step in to care for COVID-19 patients

STEVEN ROSS JOHNSON

The country's home healthcare providers are preparing to see a rise in demand for their services as more elderly patients and those with underlying health conditions stay home to lessen their risk of exposure to COVID-19.

Source: Modern Healthcare, https://www.modernhealthcare.com/home-health/home-healthcare-looks-step-care-covid-19-patients

Medical Home Care Delivery

What we know (Input Data)

- Healthcare providers information (location, expertise…)
- Patients medical info and locations

What we need to decide (Decision Variables)

- How to match healthcare providers and patients
- How to route the service fleet to assigned patients

What are the goals (Objective)

- Achieve compatible patient-provider matching
- Minimize routing cost of assignment

Vehicle Routing and Matching

To solve underlying routing and matching problems, we apply

- Integer Program
- Heuristics

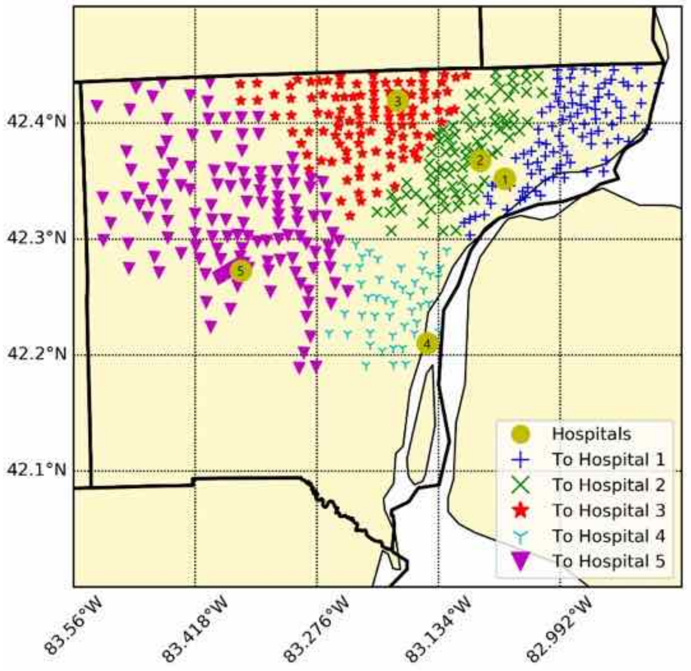


Figure: Solving MHC problems via Vehicle Routing in Wayne County, Michigan

$$\min \sum_{i \in V} \sum_{j \in V} c_{ij} x_{ij}$$

subject to

$$\sum_{i \in V} x_{ij} = 1 \quad \forall j \in V \setminus \{0\}$$

$$\sum_{j \in V} x_{ij} = 1 \quad \forall i \in V \setminus \{0\}$$

$$\sum_{i \in V} x_{i0} = K$$

$$\sum_{j \in V} x_{0j} = K$$

$$\sum_{i \notin S} \sum_{j \in S} x_{ij} \geq r(S), \quad \forall S \subseteq V \setminus \{0\}, S \neq \emptyset$$

$$x_{ij} \in \{0, 1\} \quad \forall i, j \in V$$

Toth, Paolo, and Daniele Vigo, eds. *The vehicle routing problem*. Society for Industrial and Applied Mathematics, 2002.

Outline

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- ❑ Conclusion

Supply Chain Challenges

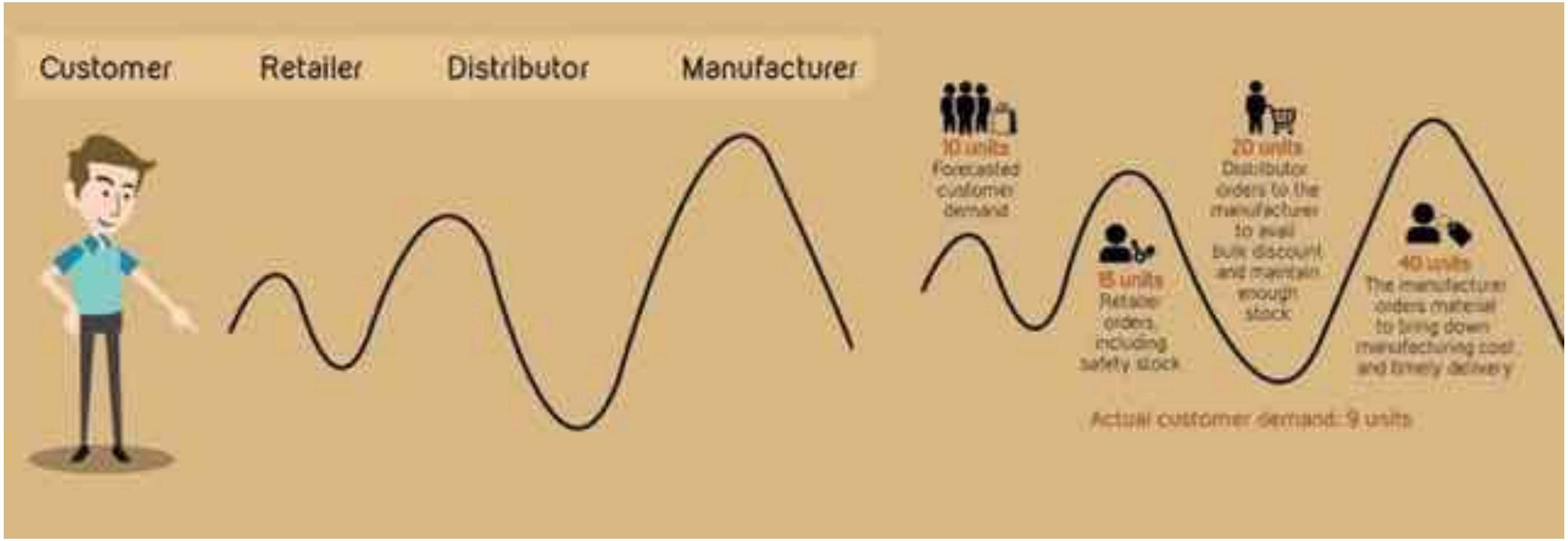
Restaurants closed down seating, but delivery drivers say they're busier than usual.

Empty shelves in supermarket.

https://www.npr.org/2020/03/22/819011691/as-restaurants-across-the-country-close-their-doors-deliveries-pick-up
https://www2.isye.gatech.edu/faculty/Alan_Erera/logistics/2020/03/23/covid-homedeliver.html

Ref: Simchi-Levi, D., Kaminsky, P., Simchi-Levi, E., & Shankar, R. (2008). *Designing and Managing the Supply Chain: Concepts, Strategies and Case Studies*. Tata McGraw-Hill Education.

The Bullwhip Effect



https://www.fibre2fashion.com/industry-article/7852/the-bullwhip-effect

Ref: Lee, H. L., Padmanabhan, V., & Whang, S. (1997). The bullwhip effect in supply chains. *Sloan Management Review*, *38*, 93-102.
Lee, H. L., Padmanabhan, V., & Whang, S. (1997). Information distortion in a supply chain: The bullwhip effect. *Management Science*, *43*(4), 546-558.

From Set Covering to Risk-Pooling

- Set-covering formulation

$$\mathcal{M}_{\mathcal{R}}: \quad \text{Minimize} \quad \sum_{R \in \mathcal{R}} c_R Z_R$$

$$\text{subject to} \quad \sum_{R \in \mathcal{R}:\ i \in R} Z_R \geq 1, \quad \text{for each } i \in I;$$

$$Z_R \in \{0, 1\}, \quad \text{for each } R \in \mathcal{R}.$$

- Location allocation risk-pooling model

$$\text{Minimize} \sum_{j \in I} \left\{ f_j X_j + \beta \sum_{i \in I} \mu_i d_{ij} Y_{ij} + w_j \left(\sum_{i \in I} \mu_i Y_{ij} \right) + \theta h z_\alpha \sqrt{\sum_{i \in I} \sigma_i^2 Y_{ij}} \right\}, \quad (1)$$

$$\text{subject to} \quad \sum_{j \in I} Y_{ij} = 1, \quad \text{for each } i \in I; \quad (2)$$

$$Y_{ij} - X_j \leq 0, \quad \text{for each } i, j \in I; \quad (3)$$

$$Y_{ij} \in \{0, 1\}, \quad \text{for each } i, j \in I; \quad (4)$$

$$X_j \in \{0, 1\}, \quad \text{for each } j \in I. \quad (5)$$

Ref: Shen, Z. J. M., Coullard, C., & Daskin, M. S. (2003). A joint location-inventory model. Transportation science, 37(1), 40-55.
Shu, J., Teo, C. P., & Shen, Z. J. M. (2005). Stochastic transportation-inventory network design problem. Operations Research, 53(1), 48-60.

Online Retailing Challenges

Under social distance, grocery delivery service becomes a lifeline.

6abc.com

Grocery delivery services trying to keep up with demand amid COVID-19

Many online grocery shoppers reached out to Action News with screenshots of what their online orders look like now, with signs that say, ...

prime now

No delivery windows are available.

All remaining delivery windows for today and tomorrow are currently unavailable. Check back for updates, or try again tomorrow.

Return to cart

Figures: COVID-19 does not only affect traditional markets, online retailing and grocery delivery is suffering as well. As Mar 27, some items are experiencing 1.5 months delay. For grocery delivery, limited delivery windows are offered due to decrease in drivers.
Source: Amazon.com

engadget

Online grocery deliveries are facing an unprecedented stress test

The COVID-19 pandemic exposes their vulnerabilities.

23 Comments · 83 Shares

Online Retailing and Grocery Delivery

What we know (Input Data)

- Current product inventory level
- Order details including products, time windows for delivery, and locations

What we need to decide (Decision Variables)

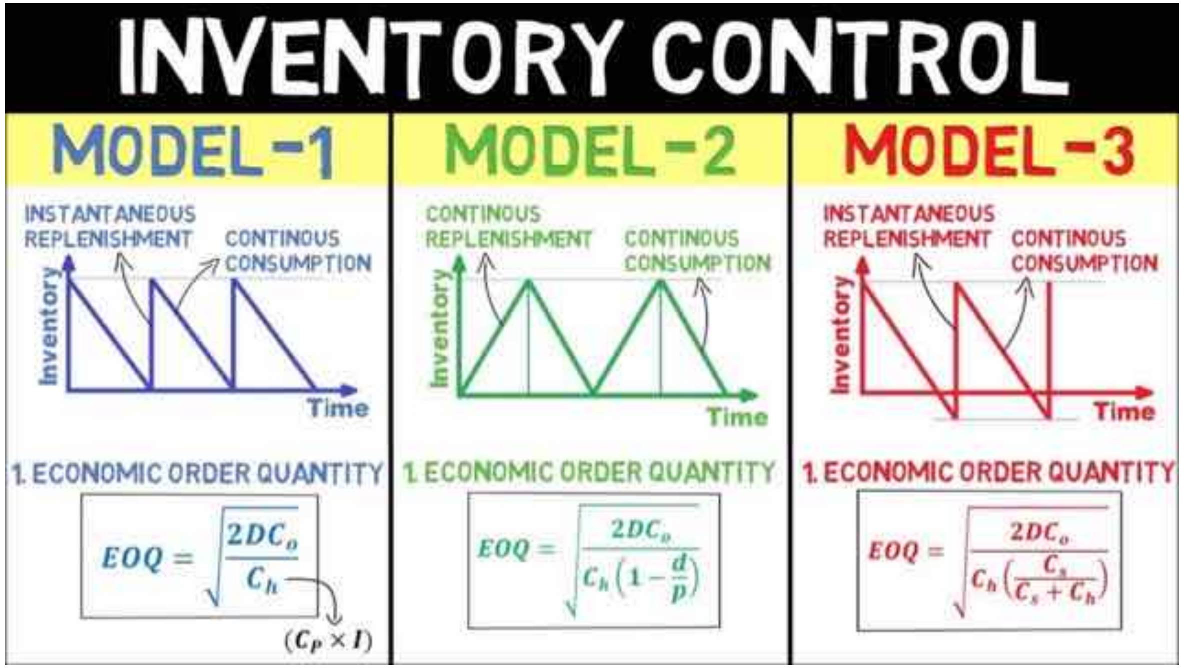
- How to replenish the inventory of each product
- How to route the service fleet to deliver grocery

What are the goals (Objective)

- Maintain heathy inventory levels
- Minimize routing cost to improve efficiency

Formulating Mathematical Models

How to Manage Inventory Control



Source: https://www.youtube.com/watch?v=n7V3_4A01q8

Vehicle Routing with Time Windows

$$\text{Min} \quad \sum_{v\in V}\sum_{(i,j)\in A} t_{ij}\cdot x_{ijv} + F\cdot\sum_{v\in V}\sum_{j\in N} x_{0jv} \qquad (1)$$

Subjet to

$$\sum_{v\in V}\sum_{j\in\Delta^+(i)} x_{ijv} = 1 \qquad \forall i\in N \qquad (2)$$

$$\sum_{j\in\Delta^+(0)} x_{0jv} = \sum_{i\in\Delta^-(n+1)} x_{i,n+1,v} \le 1 \qquad \forall v\in V \qquad (3)$$

$$\sum_{i\in\Delta^-(j)} x_{ijv} - \sum_{i\in\Delta^+(j)} x_{jiv} = 0 \qquad \forall v\in V, j\in N \qquad (4)$$

$$x_{ijv}\cdot\left(w_{iv}+h_i+t_{ij}-w_{jv}\right)\le 0 \qquad \forall v\in V, (i,j)\in A \qquad (5)$$

$$a_i\cdot\sum_{j\in\Delta^+(i)} x_{ijv} \le w_{iv} \le b_i\cdot\sum_{j\in\Delta^+(i)} x_{ijv} \qquad \forall v\in V, i\in N \qquad (6)$$

$$\sum_{i\in N} q_i \sum_{j\in\Delta^+(i)} x_{ijv} \le Q \qquad \forall v\in V \qquad (7)$$

$$\sum_{g\in G}\sum_{l\in(V-v)\cup\{v_0\}} y_{lv}^g = 1 \qquad \forall v\in V \qquad (8)$$

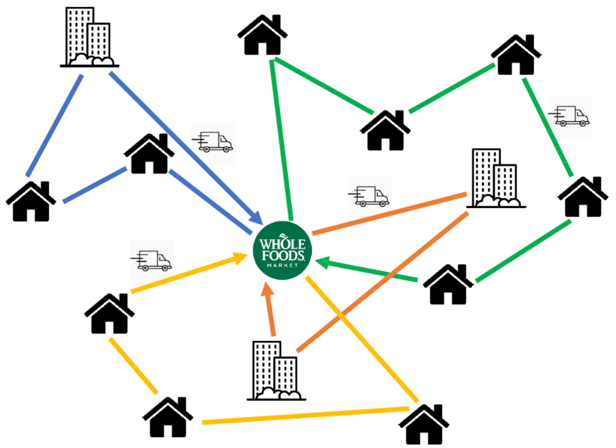
$$\sum_{v\in V} y_{v_0 v}^g = \sum_{v\in V} y_{v\bar{v}_0}^g \le 1 \qquad \forall g\in G \qquad (9)$$

$$\sum_{l\in(V-v)\cup v_0} y_{lv}^g - \sum_{l\in(V-v)\cup\bar{v}_0} y_{vl}^g = 0 \qquad \forall g\in G, v\in V \qquad (10)$$

$$\forall l\in V\cup\{v_0\}, v\in V, \forall g\in G \qquad (11)$$

$$x_{ijv}\in\{0,1\} \qquad \forall v\in V, (i,j)\in A \qquad (12)$$

$$y_{lv}^g\in\{0,1\} \qquad \forall v,l\in V\cup\{v_0,\bar{v}_0\}, g\in G \qquad (13)$$



Toth, P., & Vigo, D. (Eds.). (2002). *The vehicle routing problem*. Society for Industrial and Applied Mathematics.

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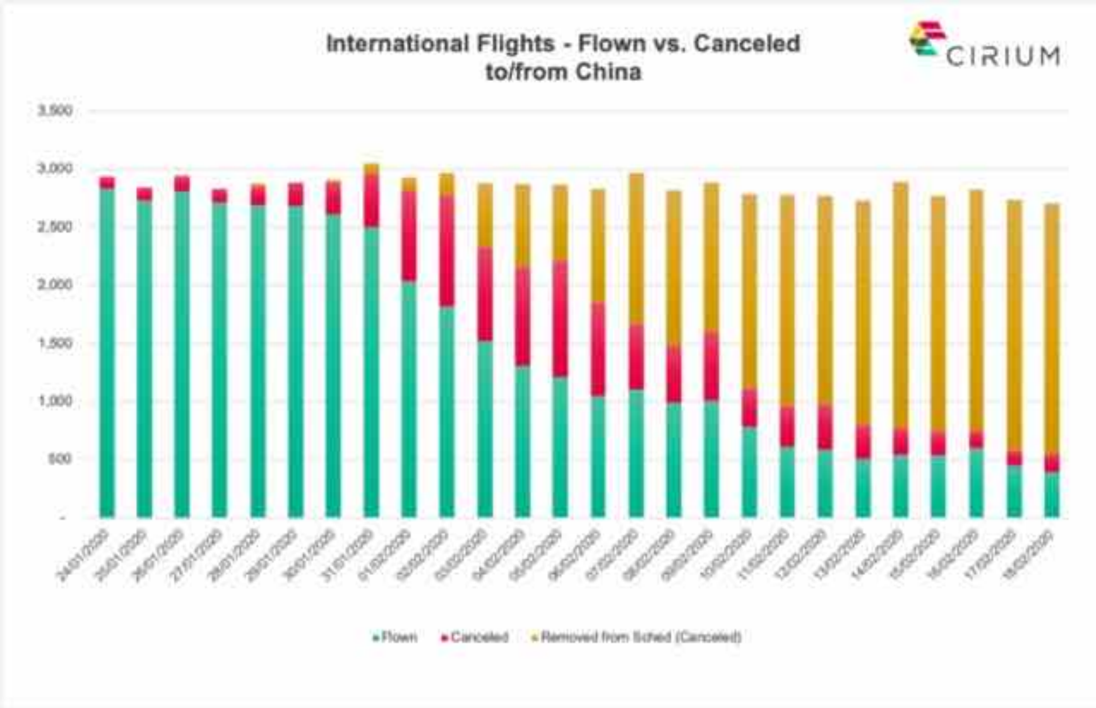
Airline Management and Airport Screening



Canceled and removed from schedule flights to and from China due to COVID-19.

People wait in line to go through the customs at Dallas Fort Worth International after US-EU travel ban in early March.

https://www.cirium.com/thoughtcloud/cirium-analysis-of-covid-19-reveals-over-200000-flights-canceled/
https://time.com/5803402/coronavirus-airport-lines/

Airline Fleet Management

- Schedule design
- Fleet assignment
- Aircraft maintenance routing
- Crew scheduling
- Origin-destination control

- String-based fleeting and routing model

$$\min \sum_{k \in K} \sum_{s \in S} c_s^k x_s^k$$

$$\sum_{k \in K} \sum_{s \in S} a_{is} x_s^k = 1, \quad \forall i \in F$$

$$\sum_{s \in S_i^+} x_s^k - y^k_{(e^{-,k}_{i,d}, e^k_{i,d})} + y^k_{(e^k_{i,d}, e^{+,k}_{i,d})} = 0, \quad \forall i \in F, \quad \forall k \in K$$

$$-\sum_{s \in S_i^-} x_s^k - y^k_{(e^{-,k}_{i,a}, e^k_{i,a})} + y^k_{(e^k_{i,a}, e^{+,k}_{i,a})} = 0, \quad \forall i \in F, \quad \forall k \in K$$

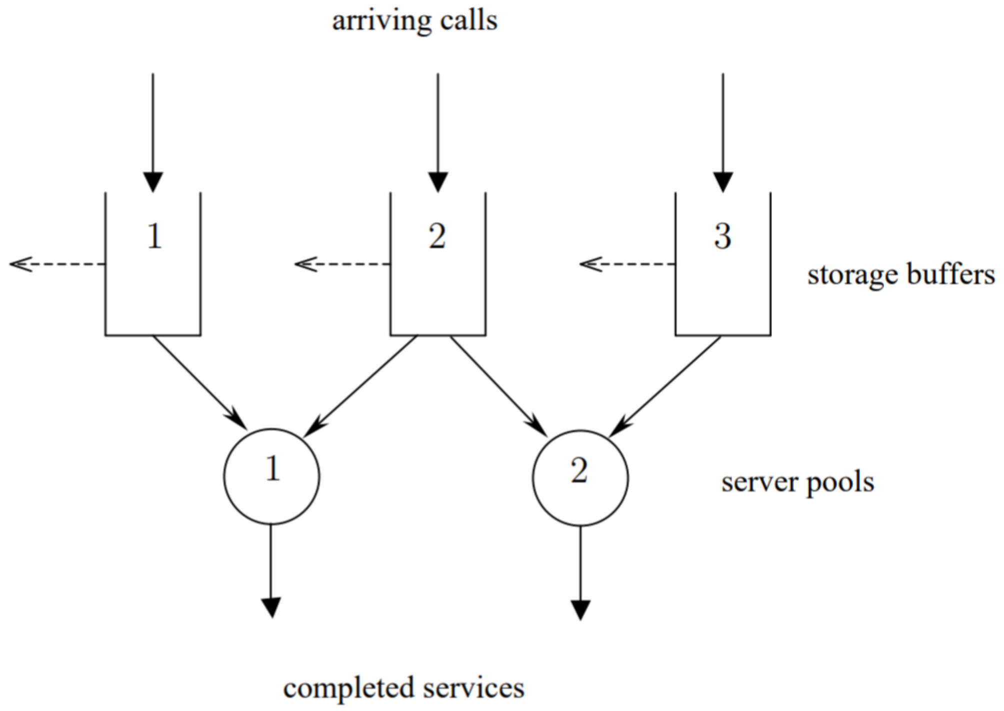
$$\sum_{s \in S} r_s^k x_s^k + \sum_{j \in G^k} p_j^k y_j^k \leqslant N^k, \quad \forall k \in K$$

$$y_j^k \geqslant 0, \quad \forall j \in G^k, \quad \forall k \in K$$

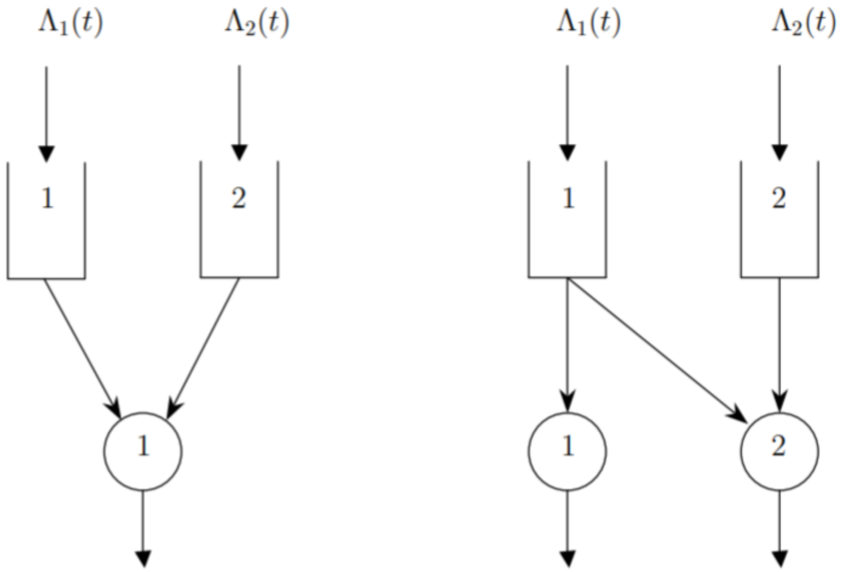
$$x_s^k \in \{0, 1\}, \quad \forall s \in S, \quad \forall k \in K. \qquad (1)$$

Ref: Barnhart, C., Belobaba, P., & Odoni, A. R. (2003). Applications of operations research in the air transport industry. Transportation science, 37(4), 368-391.
Barnhart, C., Boland, N. L., Clarke, L. W., Johnson, E. L., Nemhauser, G. L., & Shenoi, R. G. (1998). Flight string models for aircraft fleeting and routing. Transportation science, 32(3), 208-220.

Call Center Staffing: Queuing Theories



A schematic model of a call center with three customer classes and two agent pools.



Schematic models of a call center with two customer classes

Ref: Harrison, J. M., & Zeevi, A. (2005). A method for staffing large call centers based on stochastic fluid models. Manufacturing & Service Operations Management, 7(1), 20-36.

Multilevel Passenger Screening

$$\max \sum_{i=1}^{M} L_i R_i = \left(\frac{1}{\sum_{j=1}^{N} AT_j} \right) \sum_{i=1}^{M} \sum_{j=1}^{N} L_i AT_j x_{ij} \qquad (2)$$

$$\text{subject to} \quad \sum_{i=1}^{M} \sum_{j=1}^{N} MC_i x_{ij} + \sum_{i=1}^{M} FC_i y_i \leq B$$

$$\sum_{i=1}^{M} x_{ij} = 1, \; j = 1, 2, \ldots, N$$

$$\frac{1}{N} \sum_{j=1}^{N} x_{ij} - y_i \leq 0, \; i = 1, 2, \ldots, M$$

$$y_i \in \{0, 1\}, \; i = 1, 2, \ldots, M$$

$$x_{ij} \in \{0, 1\}, \; i = 1, 2, \ldots, M, \; j = 1, 2, \ldots, N.$$

Ref: McLay, L. A., Jacobson, S. H., & Kobza, J. E. (2006). A multilevel passenger screening problem for aviation security. Naval Research Logistics (NRL), 53(3), 183-197.

Impact on Low-income and Underserved

Vox

How US schools are (and aren't) providing meals to children in the Covid-19 crisis

Parents rely on schools for children's meals. Coronavirus has exposed the vulnerabilities of these programs.

By Alex Abad-Santos | alex@vox.com | Mar 28, 2020, 1:30pm EDT

SHARE

Siblings Alexander Francisco, 6, and Jovani Francisco, 8, pick up meals in Reading, Pennsylvania, on March 26, 2020. | Lauren A. Little/MediaNews Group/Reading Eagle via Getty Images

Source: https://www.vox.com/2020/3/28/21197965/coronavirus-school-shutdown-free-meals

The Boston Globe

OPINION

How will Massachusetts serve the underserved during the coronavirus pandemic?

As a physician treating underserved communities in Boston's busiest emergency department and as an elected official who represents an urban district, I'm deeply concerned for what my patients and neighbors will assuredly endure.

By Jon Santiago Updated March 15, 2020, 12:04 p.m.

A person departs Tufts Medical Center in Boston on Friday. CRAIG F. WALKER/GLOBE STAFF/THE BOSTON GLOBE

Source: https://www.bostonglobe.com/2020/03/15/opinion/how-will-massachusetts-serve-underserved-during-coronavirus-pandemic/

Impact on Low-income and Underserved

Under the COVID-19 stay-at-home order, families with low incomes suffer a series of difficulties in food and medicine delivery, COVID-19 testing.

Models presented before for grocery delivery and online retailing can be used to provide solutions to resolves those problems.

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Recovery and Post-Recovery

- Many more questions to ask when the virus spread slows down…
  - How to continue allocate hospital resources?
  - How to track re-infected patients (most having no symptoms)?
  - How to continue to perform multilevel passenger screening in hospitals?
  - How to control inbound flights from different countries?
  - How to gradually "unlock" facilities, schools, and events?
  - How to adapt to new consumer behavior and travel behavior?
  - …
- The previous "facility location" "queuing" "integer programming" "vehicle routing" and other models can be applied here, too.

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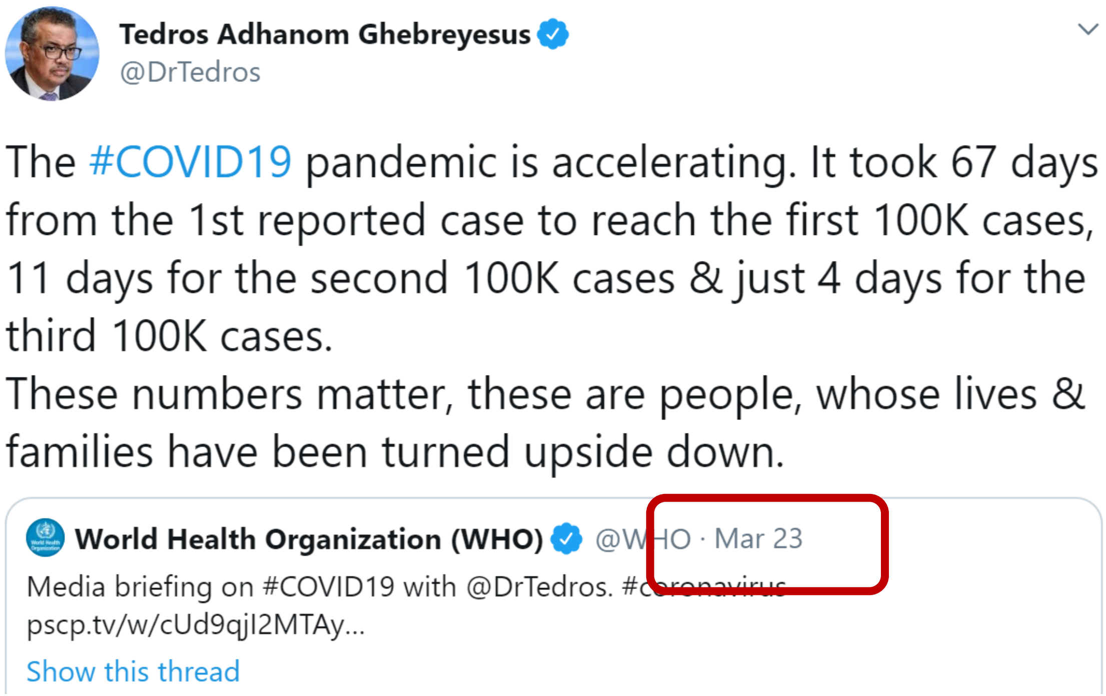
From Data to Actions, to Solutions



Tedros Adhanom Ghebreyesus
@DrTedros

The #COVID19 pandemic is accelerating. It took 67 days from the 1st reported case to reach the first 100K cases, 11 days for the second 100K cases & just 4 days for the third 100K cases.
These numbers matter, these are people, whose lives & families have been turned upside down.

World Health Organization (WHO) @WHO · Mar 23
Media briefing on #COVID19 with @DrTedros. #coronavirus
pscp.tv/w/cUd9qjI2MTAy...
Show this thread

As of April 2, worldwide we have over 1 million infected cases and over 51,000 deaths.

- **Enhancing community-based control of self-quarantine; tracking the paths of disease spread; warning people with potential high risk of infection.**
- **Increasing COVID-19 testing availability and making information transparent to the public. (Testing! Testing! Testing!)**
- **Avoiding medical supply shortage and avoiding exceeding healthcare capacity.**
- **Triaging patients to avoid cross-infection in hospitals. Gathering all patients with mild symptoms to a central quarantine place for treatment.**
- **Limiting travel and other non-essential activities, canceling social gathering, implementing `Shelter-in-Place’ and `Stay-at-Home’ policies.**

THANK YOU!

Any Questions?

Shen's personal U-M web page: www-personal.umich.edu/~siqian/

Twitter: @SiqianS

Please contact Siqian Shen (siqian@umich.edu) for any other OR/IE models and tools that you would like to add to the online document.