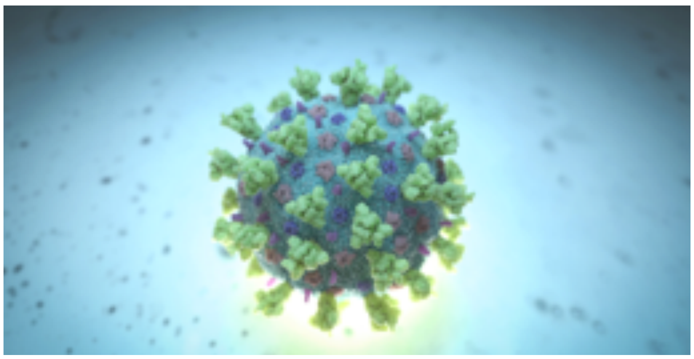
Artificial Intelligence and COVID-19:

How Pandemics will be Eradicated in the Future



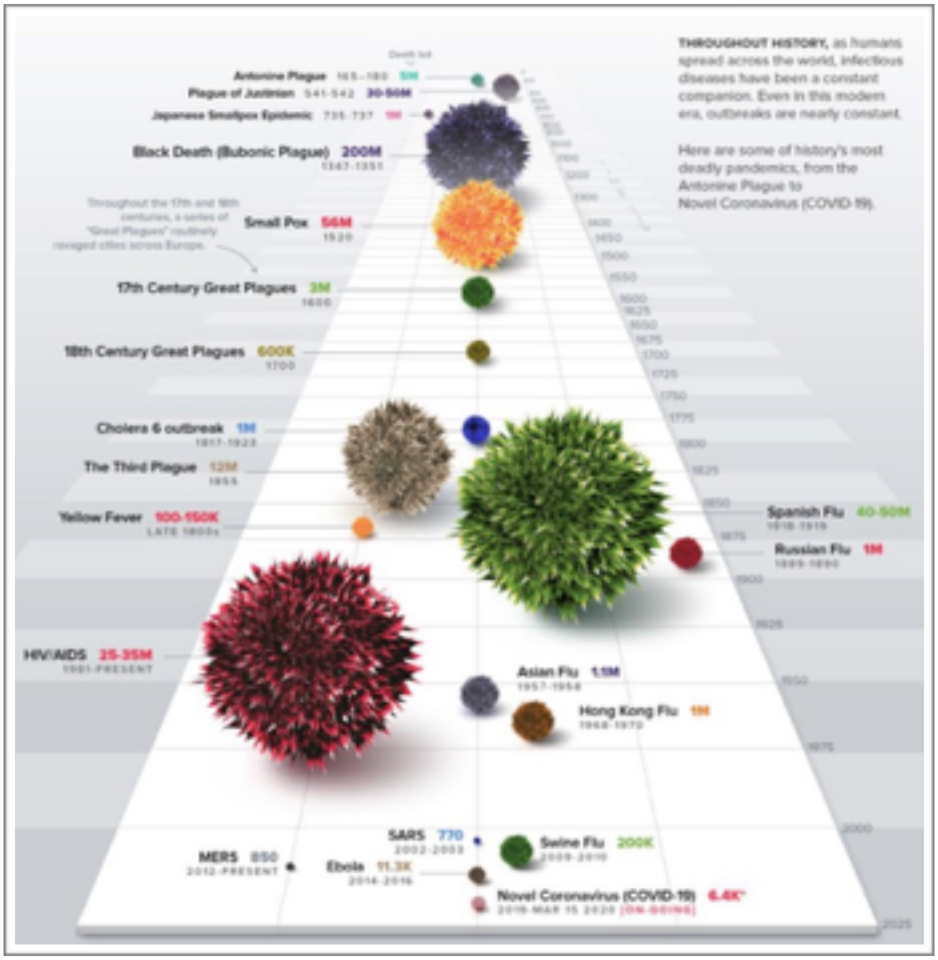
Anthony Chang, MD, MBA, MPH, MS

Founder, AIMed
Chief Intelligence and Innovation Officer
Medical Director, The Sharon Disney Lund
Medical Intelligence and Innovation Institute (MI3)
Children's Hospital of Orange County

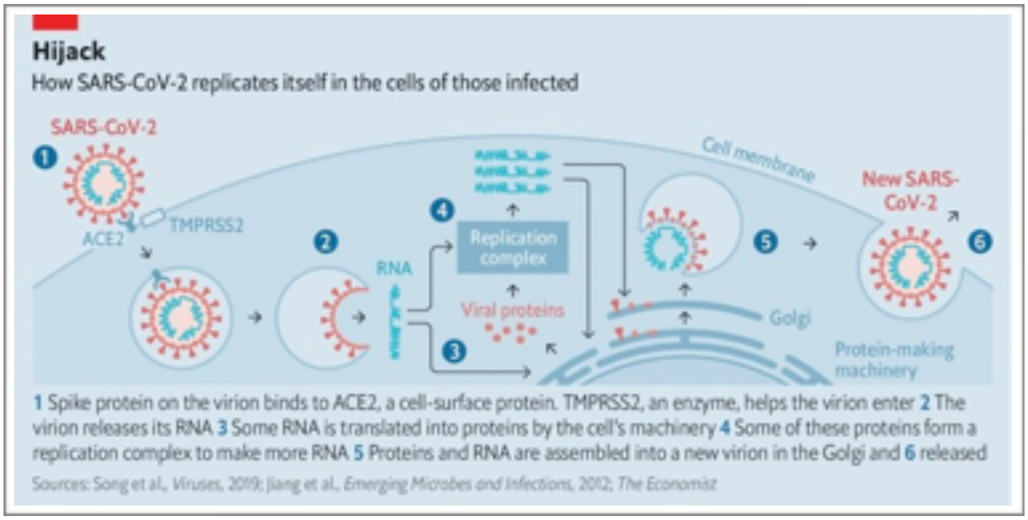
"You don't make the timeline. The virus makes the timeline."

Anthony Fauci

Introduction



SARS. MERS. Ebola. These are familiar names of recent pandemics (see figure at left from *The Visual Capitalist*) that strike fear even amongst seasoned global healthcare workers, even though the combined mortality (774, 38, and 11325 deaths respectively for a total of 12,137) was considerably less than the number of people who have already succumbed to the current coronavirus pandemic (108,333 worldwide including over 20,000 in the US of as of April 10th). The ongoing **coronavirus disease 2019 (COVID-19)** is a serious respiratory disease as a result of infection from the **severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2)**(Note: the former describes the disease entity from the latter which is the name of the virus). COVID-19 as a disease is manifested by fever, fatigue, cough, and shortness of breath, and the main pathology is ground-glass lesions in the subpleural areas of both lungs with progression to consolidation.



The **SARS-CoV-2,** a very large RNA virus, is similar to the SARS-CoV that was responsible for the SARS pandemic. SARS-CoV-2 is covered in a lipid bilayer with protein spikes, which bind to the host cell membrane via the **ACE2 surface receptor** for entry and replication. TMPRSS2 is an enzyme that aids the virion to enter the host cell.

This pandemic, now in more than 200 countries and regions and the worst since the **Spanish flu** of 1918-1919, has turned the world into a surreal apocalypse. The media coverage with its multi-colored graphics of the virus and accompanying bleak counts of cases and deaths (accompanied by horrid pictures of patients on the floor in the hospital gasping for air prior to dying) has been difficult to watch. As a comparison, the most recent pandemic of the **novel influenza A virus H1N1** in 2009-2010 (the so-called "swine flu") lead to about 60 million cases with about 275,000 hospitalizations and 12,469 deaths in the United States alone (151,700 to 575,400 deaths worldwide).

The following is a discussion of how artificial intelligence will need to be part of global health in its fight against present and future pandemics. First, an epidemiology and pandemic **primer** frames the ensuing three-part discussion. The first segment focuses on current **strategies** for overcoming a pandemic and how countries have performed to date. The second section discusses the early **lessons** learned during this pandemic and how these lessons are relevant to data science and artificial intelligence. The third and last part delineates how artificial intelligence will be leveraged as an essential partner for human clinicians and global healthcare in the **future** for pandemics.

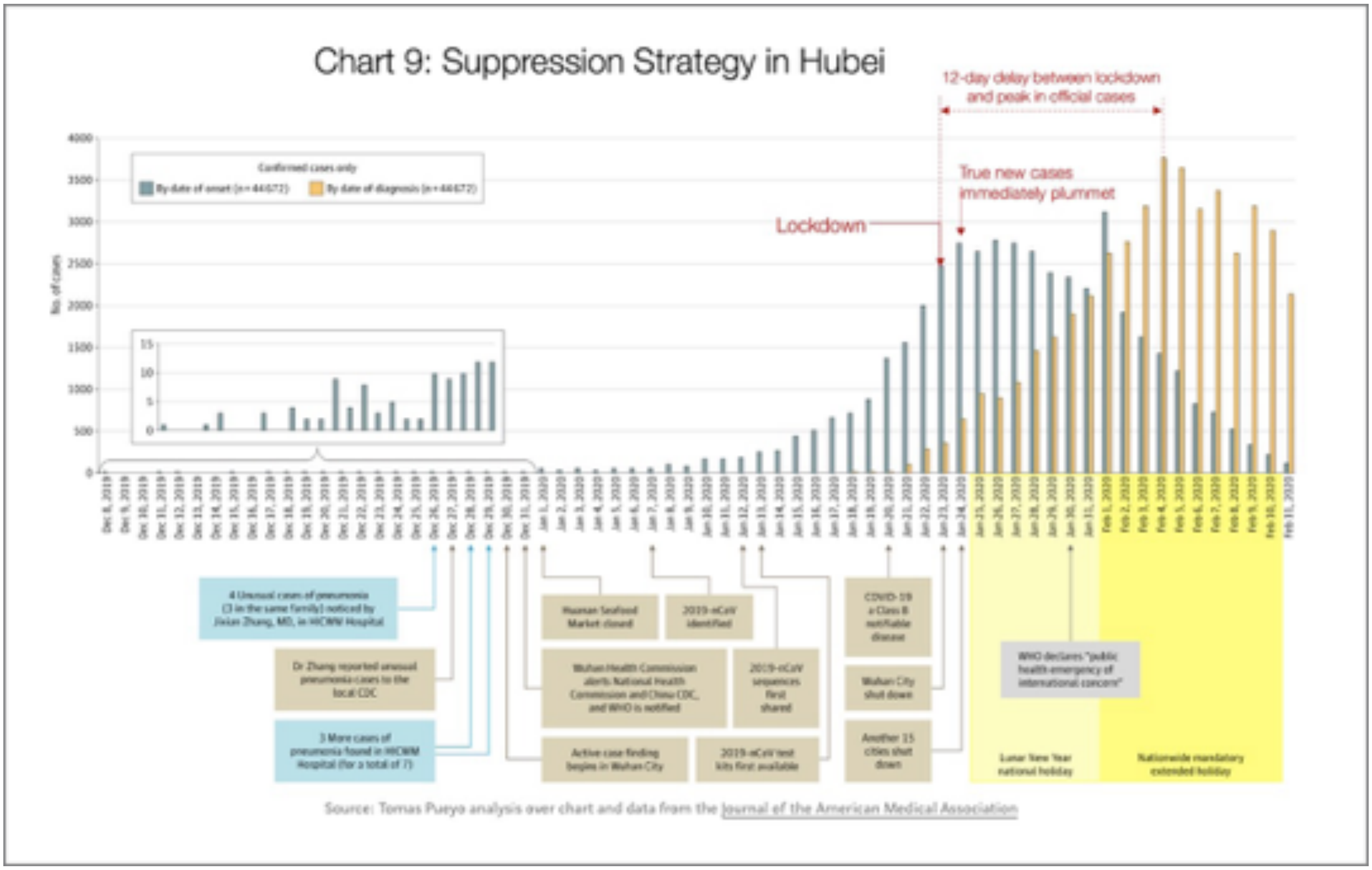
Pandemics: An Epidemiological Primer

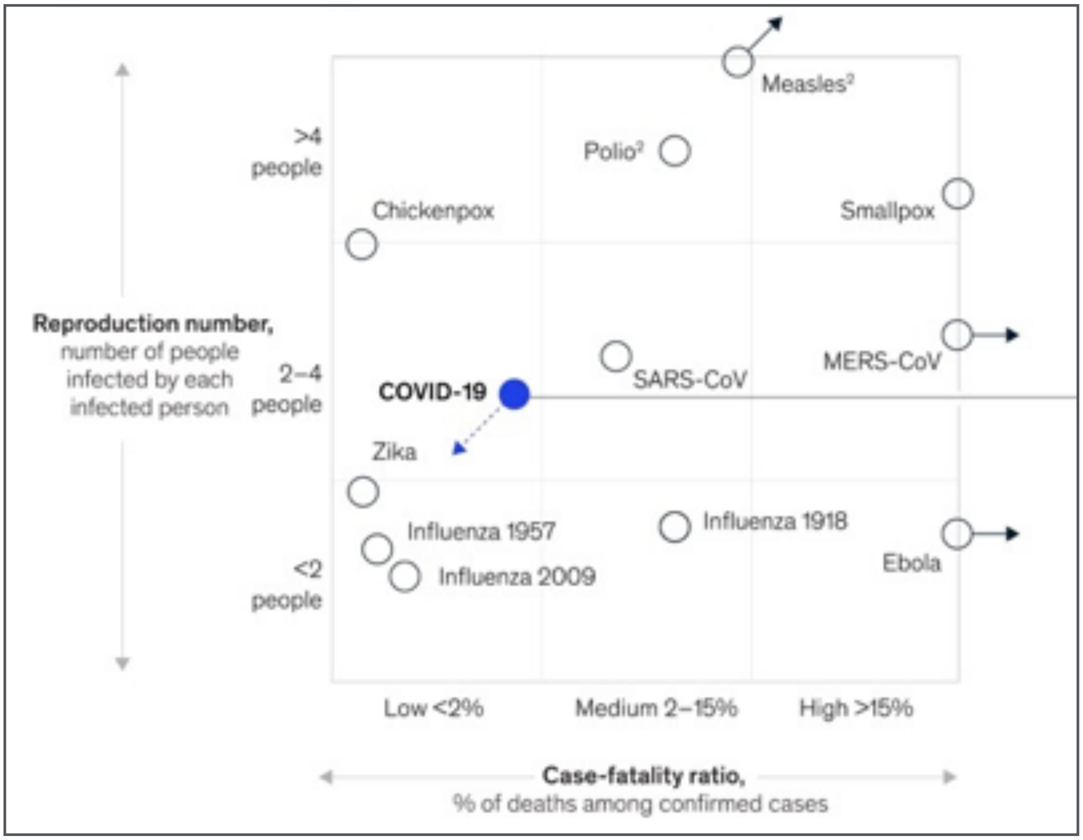
There are several important epidemiological terms and concepts in the context of a **pandemic**, which is large **epidemic** (the latter defined as an outbreak of a disease that affects many in a population in a particular region or country within a short time) that has spread to involve an entire country or several countries or regions; there is no set number of countries or regions for this global aspect of a pandemic.

A broad testing protocol at an early stage (especially if some individuals are relatively asymptomatic) coupled with contact tracing and surveillance is essential for discovering the true number of new cases that is the underpinning of a successful containment strategy.

The **testing** of the virus consists of a nasal or throat swab for testing genetic materials of the virus via polymerase chain reaction (PCR) or a serological test for antibodies. Testing is an essential part of early management of an epidemic or pandemic and has been a continual discussion and controversy in the news. Singapore had an aggressive testing program with over 12,000 people tested per million as of April 10th (compared to only 1 per million in the United States in early March). A broad testing protocol at an early stage (especially if some individuals are relatively asymptomatic as in this pandemic) coupled with contact tracing and surveillance is essential for discovering the true number of new cases that is the underpinning of a successful containment strategy (see later description). This is probably the singular reason for high level of success seen in countries like Singapore and Taiwan (although both countries are experiencing a second wave partly due to people returning or visiting these countries).

One key concept is the **incubation period** (or **delay** in diagnosis): it is the 2-14 days between time of actual SARS-CoV-2 infection to time of symptoms (which then can lead to a positive test). Even though the lockdown in Wuhan had an immediate impact (calculated in retrospect by back tracking the status of all the true new cases), the number of new cases in the news at that time did not reflect this downward trend until 12 days later (due to the incubation time)(see figure below from: Wu Z and McGoogan JM. Characteristics of and Important Lessons From the Coronovirus Disease 2019 (COVID-19) Outbreak in China. *JAMA* (February 24, 2020) and Blog post authored by Pueyo T. Coronavirus: Why You Must Act Now. March 10, 2020).





In addition, the **contagiousness** of an infectious agent can be measured by reproduction number **R_0** (pronounced R-naught), which is the estimated number of people that any infected person can transmit the infectious agent. While the typical influenza has an R_0 of about 1 and measles has an R_0 of about 16 (perhaps the highest of any infectious disease), R_0 for SARS-CoV-2 is estimated to be about 2.0-2.5 (so more contagious that the average flu but less contagious than SARS, MERS, or Ebola, all with R_0 of 4 or greater)(see accompanying figure from the WHO). Contagiousness, however, needs to be in the context of time of manifestation of the disease, as a major challenge of COVID-19 has been the lack of obvious symptoms for many especially during early phases of the infection. In other words, if there are no obvious signs and/or symptoms of any infectious disease, one can infect many without knowing. Finally, the ultimate "bad" virus would have the following characteristics: high case fatality rate like Ebola, high contagiousness (R_0) like measles, and long incubation time with majority of hosts with little or no early symptoms like SARS-CoV-2.

Contagiousness can be mitigated with measures such as aggressive testing, hand washing and sanitizing, contact tracing, temperature checkpoints, travel restrictions, and bans of gatherings above a certain size; more stringent measures include: closing sports events and bars and restaurants, closing of schools, and home quarantines except for food and urgent services (which can close as well).

In addition, there is much confusion and consternation with the number of **new cases:** this is often more of a reflection of number of people who had testing that turned out to be positive (in the past 24 hours) rather than the true number of new cases (which should include a much larger number of people with infection who are not yet tested). Often the number of new cases is increasing fast but is in actuality due to more people getting access to the testing (therefore there are more positives or cases simply based on more people having access to get tested as in the case in the US). Therefore, the **total cases** is the cumulative number of cases to date (including those who have recovered from the infection). In short, if testing is not widely available, the number of true new cases and total cases are usually much higher then the reported number of new and total cases (due to number of people who are infected and not yet tested and diagnosed).

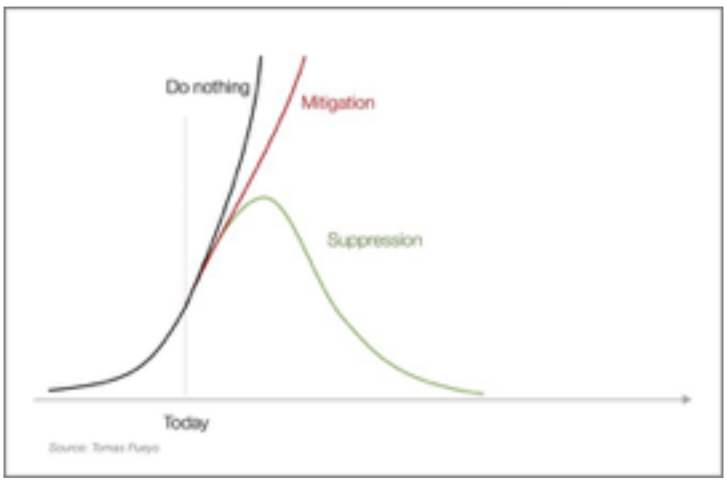
If testing is not widely available, the number of true new cases and total cases are usually much higher then the reported number of new and total cases (due to number of people who are infected and not yet tested and diagnosed).

The **case fatality rate** (in %) is the number of people dying from the disease (total deaths from disease) divided by the number of people diagnosed with the disease (total cases with the disease); it is <u>not</u> number of people dying from the disease divided by the number of people in the entire population, as that is the mortality rate. Hence the **number of deaths** from COVID-19 disease is much more reliable as an index of disease burden than the case fatality rate as number of people diagnosed with the disease is heavily dependent upon access to testing. The case fatality rate for pandemics range widely between the seasonal flu of about 0.1% (with about 500,000 deaths per annum worldwide) to 2.5% for the Spanish flu of 1918 (that resulted in 50-100 million deaths worldwide), and is most lethal at about 50% for Ebola (hence the negative publicity). The case fatality rate for COVID-19 has ranged from about 0.5% or less (Germany) to an astonishing 9.5% (Italy). The case fatality rate not only depends on the demographics of the population (as it is more lethal for the senior population) but also how capable any region's health system is in accommodating the relatively large and sudden influx of critically-ill patients. In short, the case fatality rate can be high because of: 1) relatively low level of testing (smaller denominator of the case fatality rate so the final number is bigger); 2) relatively high number of deaths from the disease mainly from an overwhelmed health system (larger numerator so the final number is bigger) or 3) both.

The case fatality rate can be high because of: 1) relatively low level of testing (smaller denominator of the case fatality rate so the final number is bigger); 2) relatively high number of deaths from the disease mainly from an overwhelmed health system (larger numerator so the final number is bigger) or 3) both.

Part I. Current Strategies for Pandemics

Although one hears about **containment** and **mitigation** often in the media, other strategies for controlling an epidemic or pandemic not mentioned nearly as often are **anticipation** (the first strategy), **suppression** (mentioned infrequently but occasionally along with mitigation), and **eradication**. Once an individual with infection is present, **containment** is a multi-dimensional strategy that quarantines (or isolates) infected or exposed individuals from the rest of the population as well as traces all the infected individuals' contacts; these measures are executed with high level of diligence. In addition, screening and monitoring of travelers at a higher risk for infection are much more effective methodologies than simplistic travel bans. **Community spread** occurs when new cases lack clear identifiable travel history related to the disease or exposure to infected individuals. When community spread occurs, containment has failed as the sole strategy and therefore mitigation or suppression have to be added as additional strategies.



The strategy of **mitigation** aims to slow (but usually not stop) the further spread of the virus. This strategy is especially designed to avoid overwhelming the capacity of the healthcare system (especially intensive care with its panoply of ventilators and ICU equipment) and concomitantly acquire **herd immunity** (which is when infected individuals in the population are immune to the infection and this process takes months to years). Mitigation is sometimes simplified as "**flattening the curve"** which is not entirely accurate as there is no guarantee of this outcome with mitigation alone (see figure when mitigation is not as effective as one would like). This mitigation strategy is executed by case isolation, home quarantines, social (more aptly called physical) distancing of those most at risk (or the entire population), and even school closures. Mitigation is akin to an "**epidemiological retreat**": a maneuver to preserve lives and to buy time. Although mitigation can potentially achieve these goals (like any retreat), its effectiveness and outcome are unpredictable.

Mitigation is akin to an "epidemiological retreat": a maneuver to preserve lives and to buy time. Although mitigation can potentially achieve these goals (like any retreat), its effectiveness and outcome are unpredictable.

A more stringent (and effective) strategy is **suppression** (perhaps too strong a word for certain parts of the world), which aims to keep cases to an absolute minimum for as long as possible; it is designed to stop or even <u>reverse</u> epidemic or pandemic growth (an "**epidemiological truce**"). Suppression advocates (in addition to the aforementioned mitigation measures) extreme social distancing and quarantining the entire population by region or country (also known as "lockdown") accompanied by school/business/event closures for a lengthy period of a few months (usually 3-6 months) in hopes to lower R_0 (contagiousness) to less than 1. As this strategy is potentially capable of not only stopping but reversing the pandemic, it is much more reliable as an intervention to flatten the curve (as compared to mitigation). The potential drawback of this suppression strategy, in addition to its heavy economic burden, is that the pandemic can recur upon lifting of this strategy since the population has not had a chance to develop the aforementioned herd immunity (which is attained with over 50% of the population having had the infection). Finally, **eradication** (an "**epidemiological victory**") is the elimination of the infection and disease, and this was achieved in 1980 with smallpox (also caused by a virus, variant of variola).

The earlier the intervention and the stronger the measures, the more effective the strategy and the less time required for these interventions; at the other end of the spectrum, the later the intervention and the weaker the measures, the less effective the strategy and the higher the number of deaths and the higher the case fatality rate.

In short, the earlier the intervention and the stronger the measures, the more effective the strategy and the less time required for these interventions; at the other end of the spectrum, the later the intervention and the weaker the measures, the less effective the strategy and the higher the number of deaths and the higher the case fatality rate (since critically-ill patients overwhelm the health system). To make matters worse, the latter horrifying scenario will require extremely stringent measures for a relatively lengthy period of time just to stabilize the very bad situation.

All of these aforementioned strategies (which can be "on" or "off" for varying time periods depending on how good or bad the situation is) are aimed at reducing the death toll with varying effectiveness and outcomes, and the outcomes of these strategies are also related to the timing and availability of effective therapeutic options (such as vaccines and antiviral medications).

While China imposed a historic harsh quarantine after failure of its initial containment strategy, other countries like Singapore, Hong Kong, Japan, Taiwan, and South Korea have successfully reached an acceptable equilibrium: implementing containment and mitigation strategies (and less draconian quarantines) while maintaining economic stability.

Thur far, different countries have had varying successes with different versions of these strategies. While China imposed a historic harsh quarantine in Hubei province (an astounding 60 million people) after partial failure of its initial containment strategy, other countries like Singapore, Taiwan, Japan, and even South Korea (which had a slow start due to a super spreader problem) have successfully reached an acceptable equilibrium: implementing containment and mitigation strategies (and less draconian quarantines) while maintaining economic stability (see **COVID-19 Country Scorecard** below). Incredibly, Singapore and Taiwan (as well as Hong Kong), despite proximity to the initial outbreak in Wuhan, have single-digit number of COVID-19 deaths (although all three areas are witnessing a recent increase in number of cases due to imported cases). Countries with less success in maintaining this delicate balance of disease burden (and capacity mismatch) and social freedom include Italy and Spain as well as the US, where heart wrenching scenarios and ethical discussions had to take place in the midst of severely stressed health systems.

Country	Grade	Notes on Pandemic Management	Recommended Actions
China	B	- Lack of transparency during early outbreak resulted in initial large outbreak - Severe suppression with large quarantine executed well in reversing the pandemic	- Prepare for second or more waves and staying vigilant - Proactive consideration for effective vaccine
Italy	C	- Inadequate early mass screening and lack of sound containment strategy - Weak mitigation strategy and execution resulted in hospital systems being overwhelmed	- Institute mass testing to identify new cases immediately - Initiate and sustain suppression immediately while scaling capacity
Singapore	A	- Excellent early testing and containment strategy with tracing program - Good public health infrastructure and hospital systems	- Prepare for second or more waves and staying vigilant - Proactive consideration for effective vaccine
South Korea	A	- Early outbreak with a super spreader but excellent recovery with early testing and containment - Good public health infrastructure and hospital systems	- Prepare for second or more waves and staying vigilant - Proactive consideration for effective vaccine
Spain	C	- Inadequate early mass screening and lack of sound containment strategy - Weak mitigation strategy and execution resulted in hospital systems being overwhelmed	- Institute mass testing to identify new cases immediately - Initiate and sustain suppression immediately while scaling capacity
Taiwan	A	- Excellent early testing and containment strategy with tracing program - Good public health infrastructure and hospital systems	- Prepare for second or more waves and staying vigilant - Proactive consideration for effective vaccine
USA	C	- Below average public health infrastructure coupled with weak mitigation and execution - Expertise in public health neutralized by poor handling of testing and fragmented leadership	- Institute mass testing to identify new cases immediately - Initiate and sustain suppression immediately while scaling capacity

The overall performance of the US leadership and health system during this pandemic has been fragmented and dysfunctional. There was the perfect storm of failures in public health: denial of the seriousness and urgency of the pandemic; lack of large-scale testing at early stages (including a faulty start); and lack of unified and effective containment and mitigation strategies.

The number of confirmed COVID-19 cases in the United States today is now well over 500,000 (with the true number probably 10 times higher or more due to lack of access to testing in some areas) with well over 20,000 deaths (as of April 10th). The overall performance of the US leadership and health system during this pandemic has been fragmented and dysfunctional. There was the perfect storm of failures in public health: denial of the seriousness and urgency of the pandemic; lack of large-scale testing at early stages (including a faulty start); and lack of unified and effective containment and mitigation strategies. This situation was made even worse for three vulnerable populations: the uninsured, the illegal immigrants, and those without paid sick leave as these subgroups all lack desire to be tested for the virus (positive test has potentially dire consequences). The imbroglio has made the leaders look overwhelmed and even visibly shaken (the US Surgeon General announced at one time with a frightened countenance: "This week is going to get bad" as his public statement).

Despite a prior pandemic (H1N1) that started on US soil a decade ago, the US was utterly unprepared and is near chaos. With relative conservative estimates based on an R_0 of 2, an infection rate of 25-50% (depending on how much the epidemic curve is "flattened" by relatively weak and inconsistent mitigation and suppression measures), and a mortality rate of 0.5-1.0% (assuming adequate hospital staffing, space, and supplies), there is a good possibility for US to have a lower range of 100,000-250,000 to a higher range of 2 million or more deaths in the US (potentially more deaths than American lives lost during all the wars combined, including the Civil War). There is, however, the possibility that the virus may have a premature exit during the summer months and/or become attenuated due to unfavorable mutations (both characteristics of RNA viruses) so that the death toll can be significantly less than the aforementioned bleak numbers.

In short, the US is paying a very heavy price (economic and human) for an inadequate and underfunded public health infrastructure to deal with pandemics as well as excessive tolerance for the individualism ethos (that resulted in soft and ineffective interventional measures early on), and now playing an exceedingly difficult "catch up" compounded with fragmented leadership that has not engendered trust in the public. The hope is that the overloaded healthcare system with its dedicated staff can partly take on the upcoming burden and that the virus may dwindle on its own in the ensuing months to minimize the fatalities.

Part II. Global Health Lessons Learned

Three important global health lessons learned during this pandemic based on performance of the international community are discussed below with relevance to data science and artificial intelligence:

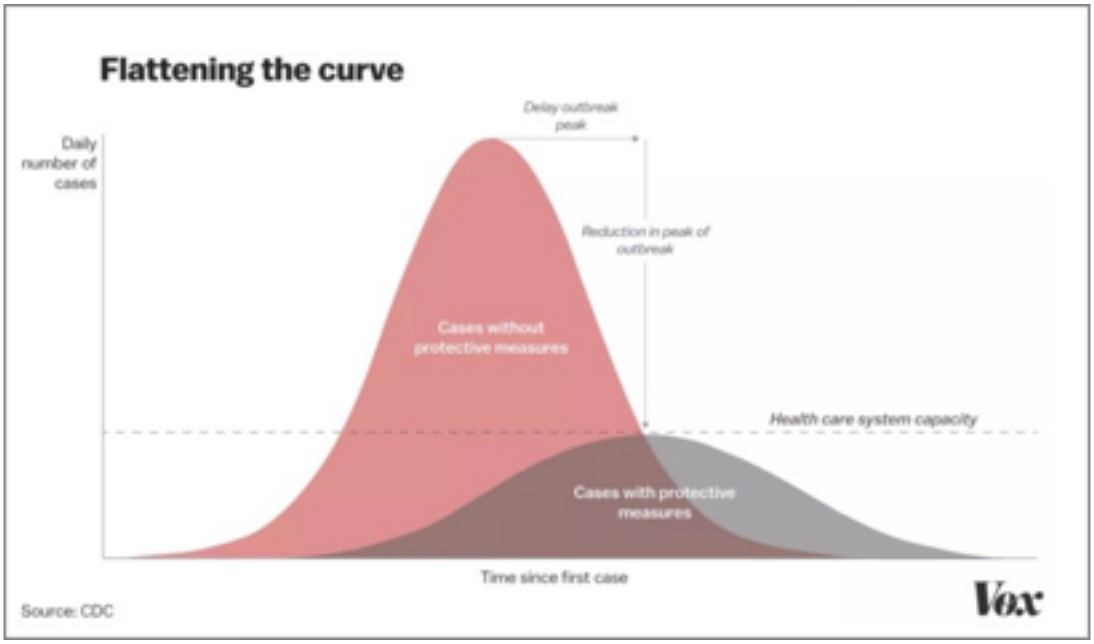
Lesson #1: Early mass testing for the infection and organization of database need to be accurate and complete for a successful containment strategy. Testing mainly in the form of polymerase chain reaction (PCR) for viral genetic material needs to be early and ubiquitous but many or most of the infected people are not tested in certain countries for SARS-CoV-2 (so it is exceedingly difficult to follow true number of new cases or to calculate the case fatality rate for this virus). Serological testing for anti-viral antibodies will be a part of recovery phase from the pandemic. Whether there will be a breakdown of the health care system or not depends on this crucial early data as it reflects a real-time status of the disease and its burden. This collected data ideally should be made available to the international community in real-time for analysis. As elaborated earlier, the earlier a country institutes these relatively heavy measures of isolation, the less number of people will get infected and therefore the less time that these measures will need to be in place. The more proactive one is about **mass testing** and the smarter one is about data and **data organization**, the less one needs interventional measures for longer periods of time (and therefore the lower your economic burden will be). The data on infected individuals will need to be coupled with **public health measures** to contain these individuals and trace others that may have been exposed.

The more proactive one is about mass testing and the smarter one is about data and data organization, the less one needs interventional measures for longer periods of time (and therefore the lower your economic burden will be).

Taiwan and Singapore executed aggressive case identification and surveillance coupled with smart use of data and databases to give real-time feedback to measure effectiveness of public health interventional strategies. Taiwan was exemplary in its proactive case identification approach in gathering data into a large database (combining native population with the visitor database) based on travel history (even supported by a QR code) and clinical status. This aggressive pursuit of accurate data included public health officials boarding planes traveling back from Wuhan back in December to examine patients. This pandemic data program was under the direction of Taiwan's National Health Command Center and included an exhaustive list of 124 action items, including an aggressive tracing program (to identify all the people the infected person has come in contact with). A combination of aggressive testing and tracing has also decreased the initial exponential growth of the virus in South Korea after a super spreader infected many at an early stage. Counter to our American experts' opinions, we need to test not just everyone but everyone serially to identify those who become infected after an initial negative test in order to contain absolutely everyone with the infection (an initial negative test does not give one immunity).

In short, we need to proactively test everyone and follow new cases during the early stage of disease with a robust database and couple this strategy with an early aggressive containment, mitigation, or suppressive strategy to minimize mortality and economic burden.

Lesson #2: Continual disease predictive modeling is essential for real-time accurate information to predict resource allocation and to minimize mortality. There has been excessive uncertainty and guesswork in projections during this pandemic, especially in the US; the best graphic the American experts can elaborate on is the now well-demonstrated one with two curves (see figure): a curve with no interventional measures that is a taller curve vs one with some measures which is a curve with lower amplitude (flattening of the first curve). These curves, usually accompanied by a dotted line signifying hospital capacity, simply illustrate that mitigation (or more stringent measures) as an intervention can result in less mortality over a longer period of time, but there is usually no defined timeline on the x-axis nor number of people on the y-axis. Data science can be coupled, therefore, to global health crises so that there is much more certainty and less chaos (the latter promulgates public hysteria). Discrepancy between projected numbers and real on-the-ground numbers can be continually reconciled as there is a myriad of moving elements. Everyone should learn to appreciate that each hour or day can matter greatly as the growth of the number of infected people is not linear but **exponential**; each period of time, therefore, has immediate sequelae of many more cases and more deaths, and this bad situation is further compounded by insufficient healthcare resources (which leads then to unnecessary deaths and increased case fatality rate). These models have to accommodate many nuances such as geography and climate, population demographics, early herd immunity, number of travelers, healthcare resources, interventional measures and compliance, degree of clustering, etc; these factors will need a **nonlinear approach** and more modern techniques (including deep reinforcement learning) to analyze the data in a meaningful real-time fashion. A quick search into publications on the use of deep learning in COVID-19 pandemic yielded mainly publications on chest CT imaging rather than decision support.



If we project a 20% infection rate and a case fatality of 1% (both conservative estimates and assuming the health system is not overwhelmed), then China should have had 2.5 million fatalities; China is not even close to this number of fatalities (about 3,339 deaths to date) since an aggressive mitigation/suppression strategy was implemented as soon as containment failed. Of note, while the sight of Chinese citizens being forced into quarantine may seem unacceptable to Westerners, the sight of large groups of wanton American youths partying on the beach during a supposedly mitigation phase may be equally disturbing to some international public health observers. Several Asian countries like Taiwan and Singapore are particularly good at gathering healthcare data with modern technology and organizing this data into databases to effectively follow healthcare interventions with robust data analytics. These countries have learned hard lessons from the 2003 SARS pandemic (especially the epicenter of that pandemic, Hong Kong). In Western countries with ample expertise in data science and artificial intelligence, there is not only lack of sophisticated collection of data during a pandemic and insufficient tracing of infected individuals, but also no clear evidence that governmental agencies routinely implement more modern artificial intelligence methodologies during a health crisis. The Center for Systems Science and Engineering at Johns Hopkins and the Institute for Health Metrics and Evaluation (IHME) at University of Washington, however, have been productive and accurate.

In short, we need to leverage big data analytics and more sophisticated machine and deep learning for an accurate, real-time map of the pandemic to enable a more precise and individualized containment, mitigation or suppression measures with appropriate allocation of valuable resources to save most number of lives while not incurring an unnecessary economic burden.

Lesson #3: Therapeutic interventions, especially if public health measures have failed to have impact, need to be both innovative and expedient. The traditional timelines (in months and years) are no longer acceptable when the velocity of infection towards a pandemic is extremely fast (exponential) due to global connectedness; we therefore need therapies (vaccines or anti-viral medications) in hours and days. **Randomized controlled trials (RCTs)** with multiple phases are outdated and too time-consuming; these trials need to be accelerated in an **exponential trajectory** (to match that of our viral adversaries). Volunteers with full consent can be recruited to fulfill the need for safety trials that may be excessively lengthy with many lives lost to pandemics during that interim. Human cognition is still important to guide a therapeutic research program: in addition to vaccines and anti-viral agents, perhaps the observation that children seem to have much less morbidity and mortality can lead to good research questions. For example, is the lack of full maturity of the immune system or lung tissue or their recent vaccinations factors in their decreased disease burden?

We need to disrupt the traditional approach of multiple phases of drug trials and bend the trajectory of these trials from linear to exponential while encouraging international and multidisciplinary open collaborative efforts in order to expediently save lives.

Among the promising (but time-consuming) trials are the ones that involve a **vaccine**; the viruses (especially RNA viruses like SARS-CoV-2), however, can mutate frequently (SARS-CoV-2 has probably already done so several times) and the solutions such as vaccines or antibodies in recovered patients' serum are rendered less effective after these viruses mutate enough times. In addition, existing **anti-viral drugs** can be called into action: remdesivir, a nucleotide analog antiviral drug initially used with Ebola, is already in a clinical trial. With the genomic map of the virus already online, this promulgated an international collaboration of scientists to explore therapeutic options to treat COVID-19 with various different approaches (such as attacking viral proteins or protecting host proteins) using some form of artificial intelligence and three-dimensional protein folding analytics and **drug discovery**.

In short, we need to disrupt the traditional approach of multiple phases of drug trials and bend the trajectory of these trials from linear to exponential while encouraging international and multidisciplinary open collaborative efforts in leveraging artificial intelligence in order to expediently save lives.

Part III. Future AI-Enabled Strategy for Epidemics

Let's imagine our strategy against a fictional **COVID-29** in the future and how artificial intelligence along with public health measures can be a *tour de force* dyad in the future management of pandemics:

A small novel coronavirus outbreak (SARS-CoV-7) is detected in southern France with clinical manifestation of bleeding and seizures with an R_0 of 7.5 and a case fatality of greater than 50%. The **AI-enabled MRI scans** of the brain revealed an unusual pattern of brain inflammation and **natural language processing** as well as **unsupervised learning** (cluster analysis) are used to collect data on these patients. **One-shot learning** with **transfer learning** are deployed for ICUs around the world as an alert for these cases. In pursuit of an effective anticipation and containment strategy of the novel virus, mandatory daily testing at home (30 seconds for results) with wirelessly automated data entry immediately started for all of France and its surrounding countries.

A real-time epidemiological map is made publicly available with proactive approach for case identification and tracing of these individuals using devices for temperature monitoring (including infrared scans now required in all public areas and transportation hubs) and travel history with **internet of things and everything** (IoT and IoE). Public health measures are immediately implemented in the surrounding countries in a precise format using **machine learning**: some areas are in containment with individuals followed via their smart phones while other areas are in surveillance mode so businesses and schools are not disrupted in most surrounding regions. **Drones** with supplies are dispatched to people who reside in containment status.

Simulations of disease models using **emulators** (deep emulator network search, or DENSE) and AI are deployed to speed up simulations many times over of this small outbreak. The projected and confirmed numbers of new cases and case fatalities are reconciled using AI in the form of **deep reinforcement learning** to minimize the number of fatalities and take into account many changing nuances such as climate and demographics. Using **crowd-sourced AI** (including high school and college AI student championship teams as well as startups and NIH), and providing genomic sequencing and protein folding with structure predictions, the novel coronavirus and its complex quaternary biomolecular structure is successful delineated within 2 hours by this **collective swarm intelligence** and a list of top 10 anti-viral agents with highest benefit-risk ratios (using **generative design algorithms**) is collected within 24 hours for use in the critically-ill ICU patients. The candidate drugs are designed as well as repurposed and are immediately approved by the FDA, which had representatives as part of this process to facilitate the research. The patients and their **pharmacogenomic profiles** are delineated for therapy based on precision medicine and AI. In addition, a new vaccine is made available in 48 hours as there was already ongoing work on a universal coronavirus vaccine (following the success of the universal flu vaccine in 2025). This work is necessary as coronaviruses now mutate on an hourly basis.

After 2 months of this small outbreak, a total of 147 patients were infected with 25 deaths and AI (including training on synthetic data generated from **generative models**) is widely utilized in the management of these patients from a global database in the ICU and hospitals for the COVID-29 patients. The workers in the hospitals had access to **AI-enabled 3D-printed equipment** such as masks and gowns (without shortages of the past) and **intelligent robots** attended the COVID-29 patients while they were infectious on mechanical ventilation with weaning protocols utilizing **fuzzy logic** and deep reinforcement learning. A group review of COVID-29 at the international Biomedical Research and Intelligence Center (iBRAIN) and its Global Pandemic Prevention Task Force (collaborative international center formed after COVID-19 that claimed over 2 million lives, with WHO and CDC as well as representatives from 109 countries with a rotating directorship) include a discussion of the last pandemic of the current era, COVID-19, as a case history. No mitigation or suppression measures are necessary as surveillance and immediate containment with good individualized precision therapy obviated the need for such historic strategies.

Of note, some of the aforementioned technology is already available but we need to work diligently and relentlessly towards this idealized scenario to reduce the universality of suffering for generations to come. The quote from the venerable Dr. Anthony Fauci: “You don't make the timeline, the virus makes the timeline” should be challenged this coming decade by our mankind taking control of the human vs virus eternal struggle.

To eradicate a pandemic, we need a proactive case identification and tracing strategy by serial mass screening coupled with sophisticated real-time data science-driven modeling as well as an innovative AI-centric therapeutic program.

In conclusion: To eradicate a pandemic, we need a **proactive case identification** and **tracing strategy** by **serial mass screening** coupled with sophisticated real-time **data science-driven modeling** as well as an **innovative AI-centric therapeutic program**. This overall philosophy will separate the infected individuals from the rest of the population while preserving both the hospital capacity to care for the sickest as well as the economy.

Viruses are the near perfect **complex adaptive system** (CAS) as these machine-like automata self-organize, pursue a common goal (finding a live host to replicate), and do this without a central leader. Albert Camus described epidemics (and even more so with pandemics) as "a shrewd, unflagging adversary; a skilled organizer, doing his work thoroughly and well." Future viral pandemics (including a second wave of COVID-19 later this year and a possible third wave early next year) may very well be even more dangerous adversaries as these become even more contagious and lethal. We can surpass their capabilities with passion, inspiration, and creativity but we humans unfortunately also have greed, stubbornness, and hubris.

We do need, however, machines to arm us with artificial intelligence to combat these viruses. We need artificial intelligence to help guide us to execute an intervention that is effective and to devise novel therapies with a much shorter timeline. This **AI-inspired strategy-outcome coupling** using **deep reinforcement learning** as well as **human swarm intelligence** will minimize mortality while concomitantly preserving economy (akin to how ICU doctors titrate blood pressure and cardiac output with varying doses of combinations of inotropic medications). As Alan Turing so presciently stated: "One must design machines to fight machines".

Just as we work towards synergy between clinical medicine and artificial intelligence, there also needs to be such a coupling between **global health** and **artificial intelligence**. COVID-19, the biggest pandemic since the 1918 Spanish flu, is the current generations' world war. Going into battle with viruses without a sound public health strategy is like going to battle without armor, and going into war with viruses without artificial intelligence is akin to going to war without weapons; in both cases, the human toll is unacceptable.

Going into battle with viruses without a sound public health strategy is like going to battle without armor, and
Going into war with viruses without artificial intelligence is akin to going to war without weapons;
In both situations, the human toll is unacceptable.