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ORIGINAL RESEARCH

Stopping Covid-19: A pandemic-management service value chain approach

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Abstract

A logical strategy to contain the Covid-19 pandemic is to completely isolate everyone for 2 weeks (the incubation period of the virus). However, such a strategy can have prohibitive economic and social costs and, therefore, will be difficult to implement. At the same time, the current situation is leading to an expanding humanitarian, health and economic crisis. Based on principles of the Theory of Constraints, we propose in this article the "Shutting-down Transmission Of Pandemic" (STOP Covid-19) plan that would reliably contain the pandemic, mitigate its economic consequences, and boost societal confidence. This plan requires the implementation of four strategies over 90 days: (a) stop all international, domestic passenger air and intercity bus/train travel; (b) create administrative zones of about 1 million people; (c) stop all non-emergency cross-zonal travel except for transportation of goods, and (d) deploy an information-driven service value chain to control the spread of the pandemic within a zone.

Keywords Covid-19 · Service value chain · Supply chain management · Theory of constraints · Pandemic management

Left to its own progression the Covid-19 pathogen could spread through the world population following a logistic curve (Sanderson 2020). As can be seen from Fig. 1, in the first half of the progression, there is an exponential growth in the number of infections. The rate of growth is determined by the average number of susceptible people exposed to the pathogen by a typical infected person during their infectious phase. The spread of the virus quickens as the value of the transmission rate increases. As the number of infected people increases, the number of uninfected people declines, and the rate of growth of infections will start to reduce progressively. By the saturation point of the contagion, almost everyone would have been infected. To put this in perspective, assuming a 1% mortality rate and no seasonal effects of virus prevalence and virulence, there would be about 70 million deaths, worldwide,

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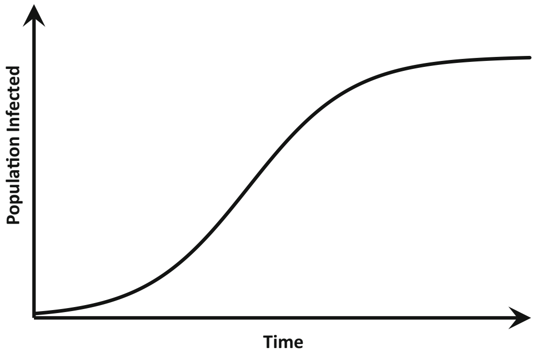

Fig. 1 Typical logistic curve

attributable to the virus. This scenario would incite panic and trigger an unprecedented humanitarian, public health and economic crisis.

In reality, there are extraordinary worldwide efforts to slow the progression of the contagion with the goal of managing the daily number of cases within the capacity constraints of the healthcare system. This approach has been referred to as "flattening the curve" (Qualls et al. 2017). Even with these efforts, there is a growing sense among experts that an extremely large proportion of the global population will become infected. Professor Alessandro Vespignani, a modeling expert on social dynamics of the spread of infectious diseases, estimates that 30–50% of the population may get infected before the virus naturally "burns out" (Bennhold and Eddy 2020). With these estimates, healthcare systems will be overwhelmed, leading to severe shortages in critical resources such as intensive care units (ICU) and respiratory support equipment. Not only will infrastructure constraints limit the ability to treat Covid-19 patients, but they will also impact the delivery of medical care to patients with other serious health issues. Indeed, such a situation has, unfortunately, already unfolded in Italy (Mounk 2020).

On the economic front, as is currently evident, businesses and individuals will respond with evolving, reactive and oft-uncoordinated responses which are likely to have cascading financial impacts. A recent HBR article (Carlsson-Szlezak et al. 2020) articulated three ways by which this pandemic will affect the global economy—(a) direct impact on consumer confidence; (b) indirect impact on confidence (wealth effect); and (c) supply-side shock. The first two mechanisms directly impact consumer and business demand, while the third causes supply disruptions which will take longer to normalize due to amplified volatility.

1 Uncoordinated piecemeal measures will lead to unacceptable outcomes

The current patchwork of measures aiming to slow the progression of Covid-19, *do not address the underlying high levels of uncertainty embedded in the time and scope of the pandemic's impact.* The lack of proactive coordination is eroding the confidence of citizens, consumers and businesses, which then reinforces the narrative that the problem cannot be contained. Strong feedback loops (vicious cycles) reinforce this process making the situation progressively worse. According to the Theory of Constraints, understanding and mapping out these vicious cycles is the key to breaking them, thereby finding impactful solutions.

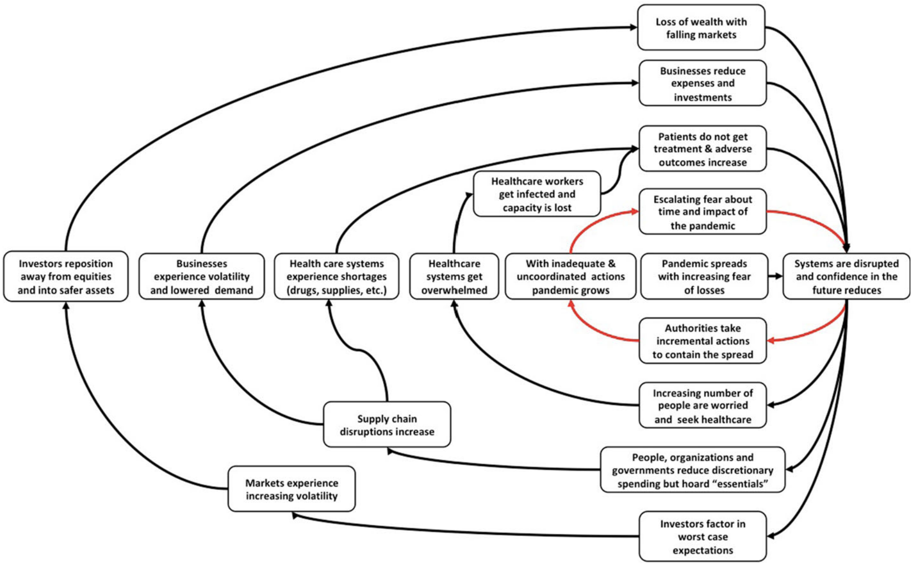

Fig. 2 Vicious cycles amplifying the crisis due to the Covid-19 pandemic

With this goal in mind, let us investigate the visual representation of these vicious cycles in the dynamic causation network diagram of Fig. 2.

As there is an escalation in the spread of the Covid-19 pandemic, an increasing number of people are seeking already scarce healthcare resources for screening purposes. This leads to increased stress on the healthcare system, intensifying shortages of critical supplies and worsening health outcomes. In addition, healthcare supply chains for essential drugs (Goel 2020), medical protective supplies (Berzon and Hernandez 2020), and equipment (Ramsey 2020) have become disrupted, driven by unpredictable isolation mandates and hoarding by panicked consumers. The lack of critical supplies due to disruptions increases the risk to healthcare workers and hospital patients of contracting the virus, thereby creating hazardous environments in healthcare facilities. These conditions manifest as loss of precious healthcare capacity due to healthcare workers themselves getting infected and, potentially, some hospitals having to be quarantined. This decrease in capacity would adversely affect the treatment of patients with Covid-19 and other critical ailments, which would intensify the humanitarian crisis and accelerate the spread of the pandemic.

Another vicious cycle captures the response of consumers and businesses. With lost confidence in the ability of authorities to manage the pandemic, consumers will pull back on discretionary spending. Businesses will experience a sharp drop in demand and start to cut back on production/services, expenses and investments. These decisions will ripple through the economy as higher unemployment and lower consumer spending, thereby intensifying the vicious cycle of reduced business activity.

An additional vicious cycle involves the financial markets factoring in the impact of the pandemic into future economic activity. As investors lose confidence in the ability of authorities to control the pandemic, they find it very difficult to quantify its impact on businesses and the economy. This leads to high market volatility as investors start reacting to emerging news. To protect themselves from the volatility and worst-case expected scenarios, investors would reposition their assets in safer investments. This change in their financial portfolios

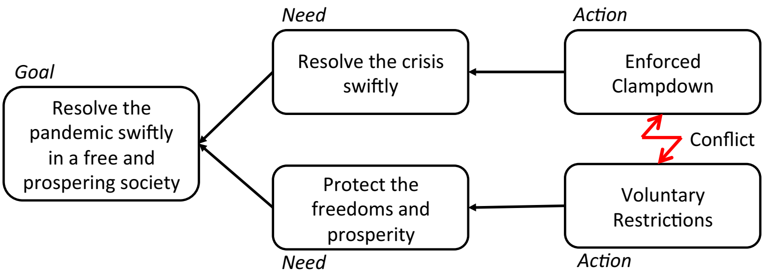

Fig. 3 Dilemma in developing the right approach to tackle the pandemic

leads to loss of wealth and further drop in confidence, thereby intensifying the vicious cycle of lower demand and discretionary spending.

Our past work with businesses and government has shown that vicious cycles cannot be broken by expecting widespread behavioral changes (Kapoor 2018). These vicious cycles can only be *broken by physical changes that eliminate the choice of undesirable behavior*. This difference between behavioral changes and physical changes is at the core of this paper's framework for controlling this pandemic. Indeed, the plan proposed in this work is squarely based on physical changes that provide a reliable expectation of success.

The physical changes needed to break vicious cycles are often difficult to implement because the associated tradeoffs represent a dilemma for decision makers. In the parlance of the Theory of Constraints, this dilemma involves a core conflict—the consequence of setting a performance objective with typically contradictory requirements, both of which cannot be satisfied simultaneously in the current setting. Specifically, for the case of the Covid-19 pandemic, the highest leverage can be achieved by breaking the innermost vicious cycle represented as a red loop in Fig. 2. If the changes required to break this key vicious-cycle are enforced, the policymakers would be confronted with the legitimate concern that citizens' freedom and liberties would be curtailed, and the economy may suffer runaway adverse impacts. On the other hand, if the changes are voluntary, then there is no guarantee of effective implementation and achieving the desired outcomes in a time-bounded manner; at best they simply delay the progression of the contagion. This dilemma is captured in Fig. 3, where the core conflict is signaled by the red zigzag arrow connecting two opposing actions.

2 Resolving the dilemma of inadequate voluntary restrictions and enforced clampdown actions

Any action that slows down the pandemic will extend the period of economic damage. On the other hand, if the goal is to stop the pandemic, then the impact would be time bounded and the healthcare crisis can also be contained. Stopping the pandemic will require a deliberate choice made by decision makers and widespread alignment around a time-bounded plan. Therefore, a clearly articulated goal of stopping the pandemic within a specified timeframe becomes a crucial first step in resolving the dilemma.

One way to stop the pandemic is by mandating social distancing in the form of a 14-day stay in place order for everyone. However, essential societal interactions, such as taking care of family members, personal emergencies, production/delivery of essential goods and

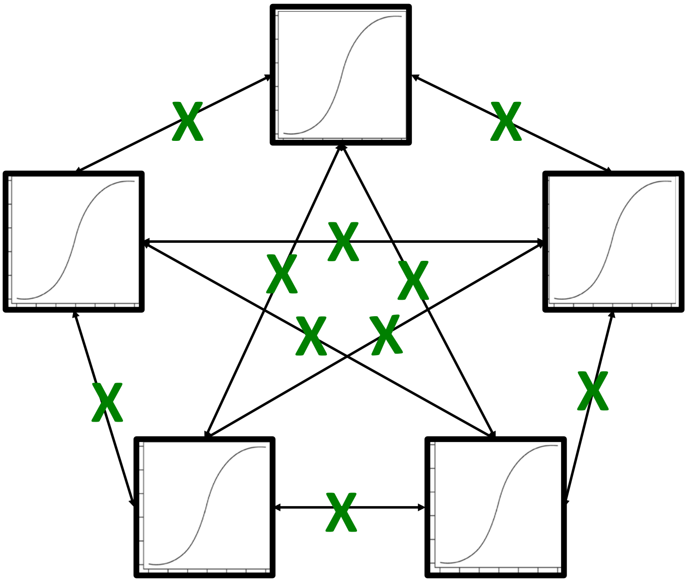

Fig. 4 Conceptual representation of cross-unit contamination across population zones

services, etc., cannot be stopped, making this plan difficult to implement due to the high economic and societal costs. Confronted with the infeasibility of the above approach, a policy of people, businesses and public/private organizations voluntarily limiting their interactions and adopting social distancing tactics is typically deployed. This approach aims at limiting the number of people exposed to infected individuals. The voluntary social distancing approach can help slow down the spread of the pandemic but has no assurance of stopping it within a foreseen time period.

To overcome this challenge, we propose an alternative approach that partitions the population into zones with specific enforced control measures to stop the transmission of the contagion across zones. Let us label a zone as "safe" if there are no cases within it or if the cases within it are isolated. Conversely, a zone is labeled "unsafe" if there is community transmission of the virus within it; i.e., the number and geographic dispersion of cases exceeds a threshold rendering the isolation strategy infeasible. The spread of the virus across zones will also follow a logistic curve with the determining factor being the rate at which an infected zone will transmit to other zones. We refer to this rate as cross-zone transmission rate (CTR), defined as the number of infections across zone boundaries per unit time. An important strategy would be to reduce the CTR by tightly controlling cross-zone transmission of infections. This is shown as an "X" in the conceptual representation of five hypothetical zones in Fig. 4.

Focusing administrative and policy measures on clamping down on CTR opens the possibility of breaking the vicious cycle by means of physical changes, rather than relying only on behavioral changes. To implement the isolation strategy for a zone, *the key constraint is the administration's capacity to enforce zonal isolation*. For example, it is possible to restrict international air travel (as has already been implemented in some situations (The White House 2020)) to reduce virus spread across national borders. On the other hand, it may not be possible to curtail travel of people across local neighborhoods within a city or suburb. Therefore, a key determinant of success is in finding the right size of an administrative zone such that (a) it is administratively feasible to check and control a small number of essential cross-boundary interactions; and (b) the time it takes for the Covid-19 infection to run its course within the zone does not exceed an acceptable threshold. Indeed, finding the right administrative zones and the right mechanisms to check and control interactions across zone boundaries, are the type of physical changes that can break the innermost vicious cycle. Such physical changes can contain the pandemic in a controlled and time-bounded manner with no runaway adverse impacts.

In view of the above problem statement, the following criteria must be met for a pandemic containment plan to be successful:

- Must be enforceable via physical changes, and not rely solely on behavioral changes of people
- Must predictably achieve the goals in a time-bounded manner
- Must be implemented by leveraging existing administrative zones of appropriate population size
- Must be followed by an economic aid package to address the direct and indirect impacts of the plan.

We suggest that the most reasonable zone size that satisfies the above criteria is a population of around 1 million with exceptions made for larger metropolitan areas. Within these administrative zones, if infections cannot be controlled in a worst-case scenario, the "saturation time" will be about 90 days[1]. This provides us an upper bound on the time duration of the pandemic-containment plan.

3 Controlling the pandemic within an administrative zone requires deployment of an information-driven service value chain

Having set up these administrative zones, the plan needs to focus on preventing a rapid spread of the virus *within* a zone. The key to achieving the containment goal within a zone depends on collecting and leveraging *information* to proactively identify test, trace, isolate and treat people, thereby reducing the spread of the virus. The traditional and widely used method of gathering information on the spread of the virus involves testing coupled with diligent contact-tracing investigations. In general, many pandemics can be contained effectively by a combination of quarantining and investigative contact tracing. For the Covid-19 pandemic, there are three significant challenges in following this strategy. First, testing capacity remains a constraint that limits the number of people who can be tested and requires prioritization for patients who are symptomatic. Second, there can be a significant time interval, from infection to isolation (with or without testing results), during which disease transmission can take place. Third, a positive test result of an individual requires a thorough contact-tracing, isolation and (possibly) further testing of the individual's contact network. This tracing task often requires an extensive expenditure of scarce investigative resources. Indeed, this task of investigative tracing is a *bottleneck constraint* that, if not alleviated, can further exacerbate testing and tracing objectives. The interdependency of tasks underlying the pandemic-management

[1] The logistic curve for the spread grows an order of magnitude every 7–14 days in the exponential growth phase. In the worst case, an administrative zone will be saturated with the entire population being exposed to the virus in 14 times $\log_{10}$(population in administrative zone). With an administrative zone of 1,000,000 people, this will be about 90 days; for an administrative zone of 10,000,000 people, this will be about 100 days.

Fig. 5 Process flow of the pandemic-management service value chain

process can be conceptualized as a service value chain[2] (Nooteboom 2007). This pandemic-management service value chain (PM-SVC) consists of the following stages: (a) *Identifying* the pool of people that need to be tested, (b) *Collecting* Samples, (c) *Testing* and *Sharing* test results, (d) *Tracing* contacts to find exposures to the infection and *Investigating* to find sources of infection, (e) *Quarantining* the positively-tested and contact-traced, non-critically ill people, (f) *Treating* infected people that require treatment, and (g) *Following-up* with quarantined people.

Figure 5 summarizes this process. The speed, reliability and scalability of this PM-SVC is critical in effectively managing the pandemic.

The Theory of Constraints, a tried-and-tested methodology, can be used for streamlining PM-SVC flows through its five-step Focusing Procedure as follows:

1. *Identify the constraint*: In the PM-SVC outlined, the constraint (bottleneck) is tracing and investigation capacity (marked red in Fig. 5). This capacity aims to answer two questions: (a) which people have come in contact with the infected person and are at-risk of being infected, and (b) where the infected person contracted the infection. Securing reliable answers to these questions requires significant investigative skills that are not easily acquired or scaled in the midst of a pandemic.
2. *Exploit the constraint*: This step refers to *managing* the constraint through a series of measures. First, trained investigators should be focused exclusively on the task of conducting investigations; all other tasks such as following up on quarantined individuals should be assigned to other support staff personnel. Second, to make best use of investigators' time, a pre-investigation, self-service, preparatory process can be developed. In this pre-investigation phase, infected people can be provided with a preparatory checklist to compile relevant information on plausible places where they could have contracted the infection, and a list of locations they had visited and people they had physically contacted during the previous week. They will be instructed to check their phone, calendar and credit card records, to recollect their activities. Third, instructions and tips can be provided on self-quarantining and protocols for seeking emergency and non-emergency medical treatment.
3. *Subordinate to the constraint*: This step refers to making the constraint a *focus* of efforts to streamline flows in the PM-SVC. Subordinating to the constraint, in this case, would involve instituting strict social distancing mandates, which would reduce the number of tracing investigations needed. Further, priority can be given to investigations that would lead to high leverage results such as finding an infection hotspot or "super-transmission" agent, etc.
4. *Elevate the constraint*: This step refers to *investing* resources in the constraint with the goal of increasing the output rate at the bottleneck stage. Here, we deploy ubiquitous, real-time mobile technologies that can assist, simplify and expedite tracing investigations. These technologies with their ease-of-access to (historical and real-time) location capabilities provide a way to simplify tracing and investigation steps. A well-structured process for

[2] Service value chains focus on creation, delivery and synchronization of interrelated services by continually adding value in response to demand for the service.

deploying technology and conducting training, along with clear specifications of roles and responsibilities, should provide the necessary scalability of the scarce, high-leverage human investigative resources.

5. *Iterate*: If the current constraint is alleviated, the above four focusing steps should be applied to the next constraint that become a bottleneck in the PM-SVC. For example, the next constraint could be at the *sample collection* stage where people need to be persuaded to get tested.

It is important to point out a key difference between our approach and the one where hospital facilities and treatment are the bottleneck constraint. Hospital facilities and treatment will manifest as a downstream bottleneck in the PM-SVC when the testing/tracing stage is not fully utilized and deployed. Indeed, the mobile technologies providing location and tracing information, coupled with powerful backend algorithms, can help rapidly and reliably track, contact at-risk people, identify emerging geographical hotspots, quantify individual/community risks, and eventually provide some high-leverage intervention points for controlling transmission, all in real-time.

On the other hand, gathering of citizens' information poses significant challenges in a free society. Unlike countries where governments collect data on citizens without the need for their permission, in a free democratic society such as the US, this data collection would require the voluntary cooperation of the citizenry. The voluntary nature of this information sharing could adversely impact its widespread adoption, thereby limiting its effectiveness. This challenge, however, can be mitigated by offering citizens a tangible *value proposition* for voluntarily participating in information sharing and an *assurance* of the privacy of their information. The citizenry's benefit of using such a government-backed mobile application (app) could be three-fold—(a) The app would offer early-warning, hot-spot visibility to citizens so they may make informed choices, (b) Based on past and current travel/contact patterns, provide real-time, customized color-coded risk-level categorization for each participating individual, and (c) In case of a participant experiencing symptoms onset, offer individualized guidance on next steps including providing prioritized testing, if needed. To address the concern of information privacy, the authorities would make three salient, firm commitments at the time of signing-up for the app—(a) the information gathered will not be used for any other purpose except in the management of the Covid-19 crisis, and not shared with any commercial enterprises or government agencies that are not directly involved in the management of the Covid-19 pandemic, (b) individuals "opting-in" to voluntarily participate will have the option to "opt-out" at any time and have their personal identification information purged from the database, and (c) when the crisis situation ends, all the collected data will be completely anonymized and only made available for research purposes. Given the value proposition and firm legal assurances, we expect a high degree of participation of citizens in the face of this unprecedented crisis.

Amid this war-like scenario, where information is imperfect, decision makers would still have to take rapid and resolute real-time decisions continually. To enable adaptive, agile and responsive decision making, we recommend setting clear strategic goals and adopting a step-by-step plan and tactics, monitored via a dashboard of metrics. Figure 6 summarizes the information-driven, intra-zonal PM-SVC approach. This approach uses a combination of physician-directed and community-surveillance testing to identify infected people (red). The community surveillance is enabled by leveraging mobile technology for (early) detection of community hotspots and transmission networks. This is followed by contact tracing, again, leveraging mobile technology to identify people who have come in contact (orange) with an infected person (red). However, there may be some contacts that "leak out" (yellow) and

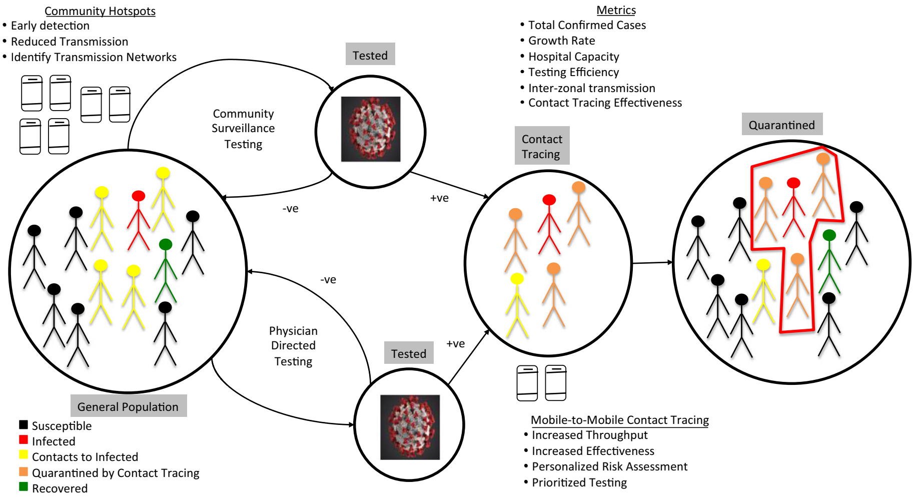

Fig. 6 Intra-zonal, information-driven PM-SVC approach

Goal: Bring transmission rate within a zone below a prescribed value in a specified time period

Strategy: Targeted identification, tracing, isolation and treatment of infected individuals

Metrics:

- *Total number of confirmed positive cases*
- *Estimates of the growth rate of total infected people*
- *Estimates of the number of infected people who have not yet been tested*
- *Average number of tests needed to find a confirmed positive*
- *Hospital Capacity Utilization*
- *Gap between the estimated number of people infected and those who are confirmed positive*
- *Number of infected people crossing zonal boundaries*

Fig. 7 Template for intra-zonal pandemic management strategy

remain unidentified in the contact-tracing process. Finally, the infected and those that are identified through contact tracing are quarantined (red-marked area).

Figure 7 presents a template for structuring the goal, strategies, and metrics, which help provide clarity and specificity on how to run the logistical machinery of information-driven actions to help manage the underlying uncertainty.

We recommend a singular focus on collecting and analyzing information that will support better and faster decision-making. Given the severe time and human resource constraints, analyses that simply explain the past and do not help make better decisions in the present should be avoided.

Having identified the appropriate administrative zone-size, time-duration and zonal-plan, we now summarize our nationwide plan to shut down the pandemic:

4 The "Shutting-down Transmission Of Pandemic" STOP Covid-19 Plan

1. Stop all international and domestic passenger travel by air, intercity bus, or train for about 90 days
2. Isolate administrative zones in units of about 1,000,000 people, with exceptions made for larger cities and metropolitan areas.
3. Create reasonable protocols for emergency travel
4. Allow transportation of goods
5. Apply the PM-SVC approach within each administrative zone

Based on an implementation of this STOP Covid-19 plan we expect a resolution of the aforementioned dilemma with focused actions that rapidly contain the crisis while protecting local economies and civil freedoms. This plan also provides a roadmap to reverse the pandemic shutdown and gradually open up the economy. The upfront economic cost of such a shutdown plan will be justifiable by the humanitarian and public health benefits. We fully expect that economic savings will ensue, stemming from a reduction in the duration and intensity of the pandemic.

We conservatively expect instances where some administrative zones will still not be successful in containing the spread of Covid-19. If the infection rate in an administrative zone crosses a prescribed threshold, over which it is no longer administratively feasible to quarantine the affected population, then we recommend isolating the vulnerable population, instituting extreme precautions in protecting healthcare workers, making strong recommendations for voluntary social-distancing, and instituting transmission-reduction measures.

Table 1 Risks and potential mitigation strategies for the STOP Covid-2019 plan

Risk	Mitigation
Supply chains will be disrupted by the proposed plan	Manufacturing and goods transportation will not be restricted. Only passenger movement will be restricted. We are assuming that the virus does not readily spread through transported goods
Public transit will still be a source of risk	We recommend that people work from home and minimize non-essential social interactions. Social distancing of this sort cannot be enforced since it is subject to the judgment of individuals. However, we do expect high levels of compliance due to the perceived personal health risk of noncompliance. Strong media education campaigns can also help build social pressure for compliance
Emergency travel outside administrative units will not be possible	Develop and enforce robust protocols for testing, travel and contact precautions for people traveling on emergencies
The transportation sector will face severe financial hardship due to the STOP Covid-19 plan	In the current situation with reactive and uncoordinated measures, the damage to the transportation sector is severe and unbounded. With this STOP Covid-19 plan, the impact will be bounded, and we recommend that the government provide a short-term assistance package to the transportation sector
The intra-zonal PM-SVC approach relies on voluntary participation and information sharing by citizens via a mobile app	In a moment of crisis, citizens rely on the judgment and endorsement of trusted and credible leaders. Therefore, first, these leaders need to be well informed on the benefits and privacy protections of this approach. Once convinced, these leaders can then credibly and publicly resolve the concerns of the citizens.

5 Mitigating the risks of the plan is vital

As with any plan, we need to also be cognizant of its risks and challenges. Every administrative zone will encounter risks and develop mitigations plans that are most appropriate for its situation. We strongly recommend setting up best-practice sharing platforms that will help disseminate effective ideas amongst communities. Table 1 provides examples of attendant risks and potential mitigation strategies.

6 Key takeaways

In this article we have presented the “Shutting-down Transmission of Pandemic” STOP Covid-19 plan to reduce the humanitarian, healthcare and economic impact of the pandemic. There is a small window of opportunity to rapidly implement this plan to avoid an uncontrollable humanitarian crisis. The following are six key highlights of the plan:

- Setting a goal of stopping the pandemic within a time bound

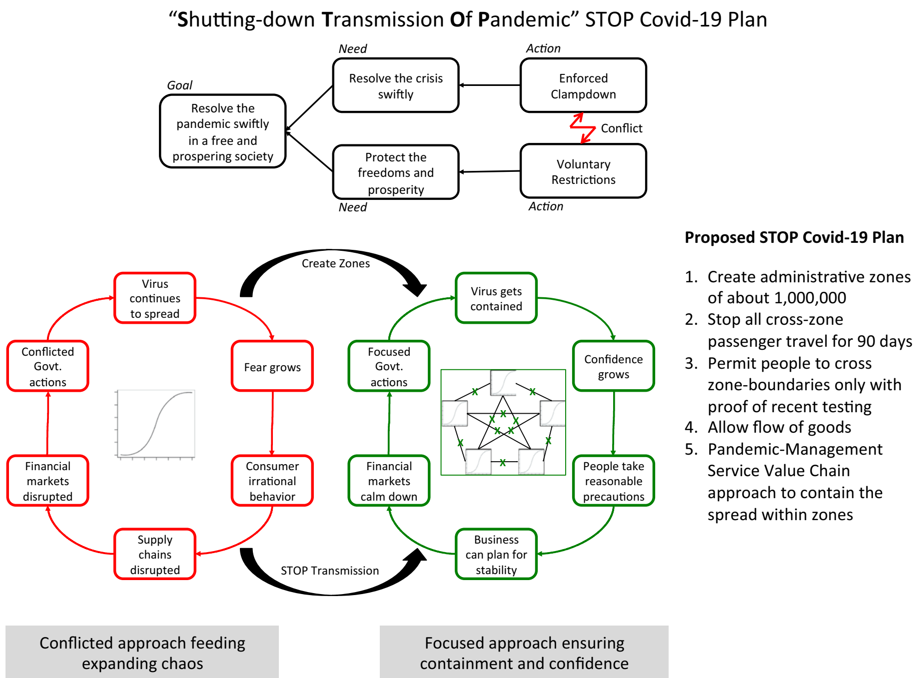

Fig. 8 The STOP Covid-19 plan at a glance

- Stopping air, bus, train passenger travel nationally for 90 days
- Creating administrative zones of about 1 million people
- Driving containment within a zone by deploying an information-driven PM-SVC approach
- Mitigating the financial impact of the plan through government-funded economic-aid packages
- Generating confidence among businesses and citizens through demonstrable positive outcomes resulting from the plan's implementation

Figure 8 summarizes the STOP Covid-19 plan.

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