



31st Annual **INCOSE**
international symposium
virtual event
July 17 - 22, 2021

Dealing with COVID-19 Pandemic in Complex Societal System for Resilience Study: A Systems Approach

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Abstract. The continuing spread of COVID-19 has triggered a global health crisis with raising a series of problems in healthcare, economics, policymaking and environment, which significantly affected the resilience of the whole societal system. We emphasize the societal system, as an adaptive and complex system, has a fundamental impact on the spread of the virus linked to individual behavior change and disaster governance system. This paper combined system thinking and resilience thinking to visualize the complexity and comprehend the governance system under global pandemic threats towards recovering the resilient society. We underline the societal system can be affected by the pandemic, and in turn, impinge on the individual behaviors and governance with a proposed multi-stage and multi-scalar framework dealt with the process from crisis to recovery. Meanwhile, a qualitative system dynamics model is proposed inspired by the general Susceptible-Infected-Recovery (SIR) model with multiple interactions and interdependency of intervention policies, human psychological factors and mobility-related factors to explore the influence on the societal system with time effect. Through this perspective, we should enhance the sense of crisis and integrate resilience thinking into the current hazards and recovery process combined with the interconnectedness among societal system in the future.

Introduction

COVID-19 in the Complex Societal System

SARS-CoV-2 is an emerging virus that causes COVID-19 (Lavine, Bjornstad & Antia 2020), which was first reported by officials in Wuhan City, China, in December 2019. Although there still is a debate on whether the Huanan Seafood Wholesale Market is the origin point of the COVID-19

pandemic, the virus has widely spread to almost all countries worldwide. On March 11th, the World Health Organization announced that COVID-19 could be categorized as a pandemic (Hynes et al. 2020), where some people never witness such a global threat in the whole life. The unprecedented and highly intricate transmission and its destructive power overwhelmed the societal immune system and certainly changed people's daily routine and behavior. Although many countries have implemented governance policies, these policies include but are not limited to shutdown borders and reduce public transportations, close school and public transportation, trace close contacts, reiterate public health guidelines, and set guidelines for the business reopen. However, at the moment this article is written, the new COVID-19 infection cases and death counts still grow vigorously with uncertainty. COVID-19 is not just a global health crisis, it is also a societal system crisis that seriously disrupts different sectors such as the global supply chain, manufacturing industries, transportation system, tourism business, etc. The management of COVID-19 spread always accompanies concordant high social costs, creating shock and difficulty for the whole societal system to absorb. To some extension, it seems the societal system has partly neglected the development of resilience against the global crisis and causing intensive uncertainty and vulnerability for the economy, ecosystem, governance system, etc. It will undoubtedly be time-consuming to recover from the crisis to a new resilient system. Even the vaccine has been invented and widely distributed in many regions, some research still indicates the virus may become endemic and continue to circulate in population for years in the post-pandemic period (Lavine, Bjornstad & Antia 2020)

Capture the Relationships and Complexity in the Societal System

To tackle the current global crisis, the relationships linked to societal system and its interactive subsystems should be analyzed. In this pandemic, virus spreads through complex and massive societal system, where every subsystem and characteristic of the societal systems play a unique role in the outbreak that one component cascades in changes or feedbacks, potentially affecting the condition of the entire complex system. The societal system can be seen as a dynamic and complex system involving many interrelated subsystems and factors (Bradley et al. 2020). Human beings, as a component of the complex system, cascade the changes and risk back to the system itself, where individual behavior will be affected by the complex system in terms of the societal-psychological-political interactions, and in turn, shape the inherently complex and dynamic societal system. Within the high complexity, self-organization and interdependency of human behavior, people with multiple socio-psychological, socio-economic, socio-natural interrelations continue affecting the spreading of the virus in the complex network (Galea, Riddle & Kaplan 2010). Moreover, the knowledge on the disease's spread mechanisms may not be fully understood, where the unknown and untraceable of how and when people get infected and how to prevent asymptomatic transmission brings challenges to the inhibit of the spread.

This is also connected to the characteristics of the complex system, where a small perturbation or interference will cause a disproportionate and non-linear system reaction resulting in the local or large-scale emergence of COVID-19. From the governance viewpoint, the virus spreads, accompanied by a relatively high fatality rate, on the scale-free network causing an exponential increase at the early stage without any strong and effective nonpharmaceutical interventions. This has created unprecedented challenges for governance that also put a societal system at high risk with considerable management difficulties. These characteristics connect and interact with each

other at a particular time and spatial dimension to accelerate or inhibit the spread and development of the epidemic.

Therefore, in this study, to tackle this wicked problem, the pandemic is discussed from a system viewpoint, which can provide the stakeholders and policymakers a big picture with multifaceted interactions in the crisis and an insight into the current and future recovery process. Moreover, as the complexity and interactions constantly acting on the societal system, affecting the emergence and spread of the new coronavirus, system thinking allows us to recognize the systemic properties and components with selecting and adapting different intervention policies at temporal-spatial dimensions. Besides, to deepen the adaptation and recovery process, we leverage the systems approach to identify the system change process linked with policy management, human behavior, and technology and build a resilience framework inspired by the classic resilience curve to show the collaborations and divergence in the crisis. Finally, we also analyze the numerous, simultaneous, causal and complex interactions and linkage by qualitative causal loop diagram (CLD) via feedback loops with time effect to illustrate the positive and negative relationships among elements and subsystems of societal system. By revealing the dynamics within the societal system, we hope to shed light on how stakeholders and related individuals learn, adapt, manage even live with interruption and uncertainty to meet the challenge in the (post) COVID-19 period.

Human Behavior, Governance and Resilience within the Complexity and Interaction

Due to urbanization and globalization, the societal system tends to be more complicated by developing information flow, technology, human activity, cultural diversity and infrastructure system. These developments interact with each other challenging the policy formulation and implementation during the pandemic and affecting the system resilience.

Resilience: an Inherent Attribute under Complex and Adaptive Societal System

Resilience is a concept that first emerged from the ecosystem. Although there is no uniform definition, resilience can be generalized as a kind of ability to assist ecosystem maintenance of functioning and return to an equilibrium state after disturbance of trauma (Madni and Jackson, 2009; Duit *et al.*, 2010). Facing this pandemic, system resilience is a crucial concept with continuing rising popularity during the COVID-19 pandemic and can be conceived as an inherent characteristic of the complex system. When the societal system confronting the COVID-19 pandemic, resilience is an ability that helps the societal system adapting any change rapidly in terms of the risk and hazards, and handles and surmounts the current crisis in an acceptable time. Here we define system resilience as the ability of a complex adaptive system to withstand a major disruption within acceptable function loss, and the capacity to minimize the negative consequences and recover from turbulence in an acceptable time and cost (Madni and Jackson, 2009; Mansouri, Sauser and Boardman Dr., 2009; Hynes *et al.*, 2020; (Uday & Marais 2015). In the COVID-19 pandemic, the overwhelmed and collapsed urban immune system, which is inconsistent with the complexity of the societal system, causes the weakness of system resilience in this outbreak. Regarding the current crisis, resilience is not the moment that the subsystems of societal system collapse and lose part of or whole functionality, such as the supply chain system, healthcare system or transportation system. On the contrary, resilience is a process that a system perceives risk,

suffers from disruption, faces up to the crisis, absorbs negative effects, adjusts itself, and constantly restores original functions. It's an ability that a system sustains the pressure from economics, operations, healthcare, human welling and recovers from the crisis and disruption (Jovanović et al. 2020). Moreover, the system resilience is continuously formatted and shaped by multiple subsystems of the societal system, including but not limited to individual activities, multiple interventions, and the technologies and measures that are used to inhibit the spread of the virus, alleviate social anxiety, sustain health and psychological wellbeing.

Governance: Managing and Responding to Uncertainty and Complexity in the Crisis

Governance system is a complex system that makes and implements decisions in pursuit of its objectives with thinking about stakeholder's benefits. In the governance area, resilience discourses are system-oriented as a hallmark of rules to adapt the change with uncertainty, unpredictability and contingency under the implementation of different policy portfolios (Welsh 2014). Different policies continuously interlace and overlap, emerging interconnectedness in inter- and intra-systems. Governance system should remain flexible, diversified and adaptive under the condition of turbulence during the COVID-19 pandemic and post-pandemic period, corresponding to the properties in the complex system. Governance system is not static and linear, where the structure connects the propagation of COVID-19 by linking human behavior, economy and the developed infrastructure system and technology. The stakeholders may center on local governance and set governance system to tackle long-term impacts on COVID-19 with the consideration of the complexity and variation in the evolving and adaptive societal system as well as build the ability to resist future shock and hazard (Duit et al. 2010). Decisionmakers at multiple levels of the societal organization make targeted policies to decelerate the spreading speed in order to recover a resilient system. From the health governance level, a series of strategies have been deployed to inhibit the continued spread, where the strategies have some similarities but with some differences across different countries in intensity, timing and implementation style. The central strategies can be concluded into two categories roughly: containment and quarantine. Containment strategies focus on prevention, such as social distancing, remote working, and wearing a mask in public areas (Djalante, Shaw & DeWit 2020). Quarantine strategies are consisting of such as isolating positive testers and suspectable close contactors. Policy should be considered from temporal-spatial dimensions with different intensities for stakeholders. The policies applied by different regions have some fundamental universalities: reducing the human-to-human physical contact and transmission chance, however, the results are quite different. Besides the cultural and psychological factors, the spatial, temporal, and policy intensity and diversity factors should also be taken into effect. We developed three-dimensional axes to expound different dimensions of the policy implementation shown in Figure 1.

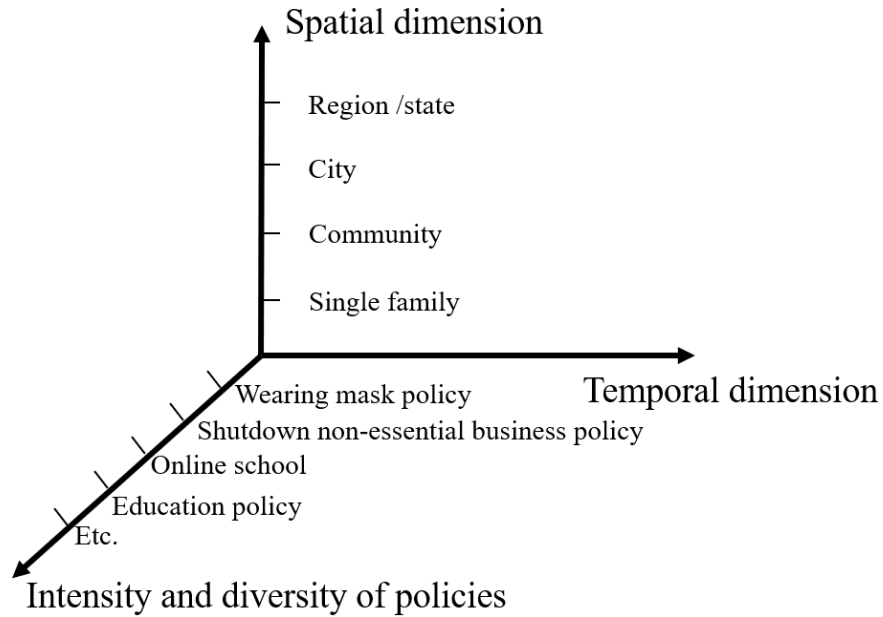


Figure 1. The Dimensions of Policy Implementation in Governance System

In the temporal dimension, the governance system may continue to optimize and change through time by considering the policy acceptance, social norms, and psychological status but mainly determined by the degree of epidemic spread. From the spatial dimension, at macro-level, governance should consider the interactions among individual behavior, technology, and infrastructure system. And the potential acceptance of the new policy should also be estimated. At micro-level, the lockdown policy can be differentiated. For example, as the epidemic evolves into different stages in temporal dimension, the administration may choose to close some communities that are considered the hotspot instead of locking down the entire city from the spatial dimension. More specifically, for example, New York State reimposes lockdown restrictions at the beginning of October 2020 tiered by the color red, orange, and yellow, while the red zones represent the hot spots with the highest positive rate and will face a near-total shutdown. Moreover, in order to improve the psychological wellbeing, some communities may hire psychologists to relieve the repressive and tense emotions within the communities at the micro-level combined with other flexible interventions. Besides, the self-discipline and self-consciousness brought by the social norm and personalized policy at the micro-level may bring positive feedback to the virus inhibition. The dimension of the intensity and diversity of the policies have a great influence on the virus spreading speed too. For instance, during the early stage of the pandemic, wearing a mask in public, especially in the enclosed space and crowded places, is mandatory by most authorities in Asia. Singapore is a typical example, making it compulsory to wear masks in public in April 2020. First-time offenders caught without a mask will be fined S\$300 (\$212). At the time, Singapore only has a little over 3000 confirmed cases (Cheng et al. 2020). France, a European country with a relatively high death rate, mandated masks for schools and transport in May 2020. At the time, over 130,000 people have already been infected by new coronavirus (Horwell & McDonald 2020). When France government finds out this mandatory is not enough to stop the virus from spreading, they mandate masks indoors in July 2020 and all public areas in August 2020 (Hoertel et al. 2020), where the total infected counts almost doubled from May to over 250,000. By comparing the

sample of Singapore and France, it is obvious that the implementation of appropriate intensity and diversity policies in a temporal-spatial dimension may cause a difference in virus inhibition in address the global pandemic.

Human Behavior: Constantly Configuring the Governance System and Resilience

In the current complex and dynamic societal system involving human behavior, wellbeing, policymaking and system resilience, any change can be cascaded even amplified to the whole system by the interconnection and feedback, such as the unprecedented emergence and outbreak of COVID-19. Individuals are the most essential component of the societal system. The virus spreads through the people's daily activities, keeps evolving, and then spreads out via the complex infrastructure system. This spreading process is from the bottom to the top leading to the emergence property of the system, while the policymaking process is typically from top to bottom, causing more dynamic and uncertainty linked to behavior change (Wang, Xu & Mansouri 2020). Adaptation and variation of people's behavior and activity can change the spread of virus on the complex network and, in turn, be reconfigured by the governance system linked to culture, climate, social norm, information flow and psychological and economic factors. However, the societal system can amplify both beneficial and harmful behavior change over time, so how to govern individual behavior is one of the biggest challenges that the governance system faces in the context of the pandemic.

Moreover, the individual's complexity is determined by multiple reasons like culture and tradition. In addition to the execution of compulsory policy, the governance system should imperceptibly educate and advise individuals to take protective actions. For instance, wearing a mask during daily life is more acceptable among Asians, such as Chinese, Singapore and Korean, simply because they learned from the 2003 SARS, which is a similar respiratory disease with a high fatality rate. Besides the historical experience, people in Asia could be wearing a mask all four seasons for many reasons, such as suffering a heavily polluted season, an extra layer for warmth, or fashion. Based on Asians' mask-wearing practice, the mask or cover shield wearing policy can be easily introduced and implemented to slow the epidemic. Where in some western areas, however, masks are generally much less popular because of the cultural difference. In some Western countries, like some regions in Europe, it's assumed that masks are associated with sickness or crime. During the early stage of the pandemic, some people panicked simply by seeing others wearing a mask (Bavel et al. 2020). The example reveals the complexity of governance related to human behavior. Not only the interconnectedness between policies, but also the interaction and connection among culture, psychological, and economic factors should also be taken into consideration against the systemic threats to improve resilience (Jovanović et al. 2020).

Stage of Resilience

In order to broaden the scope of attention, aiming at the system resilience and better governance from vulnerability to fully recovery, a framework with multi-stage and multi-scalar of resilience inspired by the classic resilience curve (Hynes et al. 2020; Jackson & Ferris 2013) with considering of complexity and causality in the societal system is developed to assess the systemic threats shown in Figure 2.

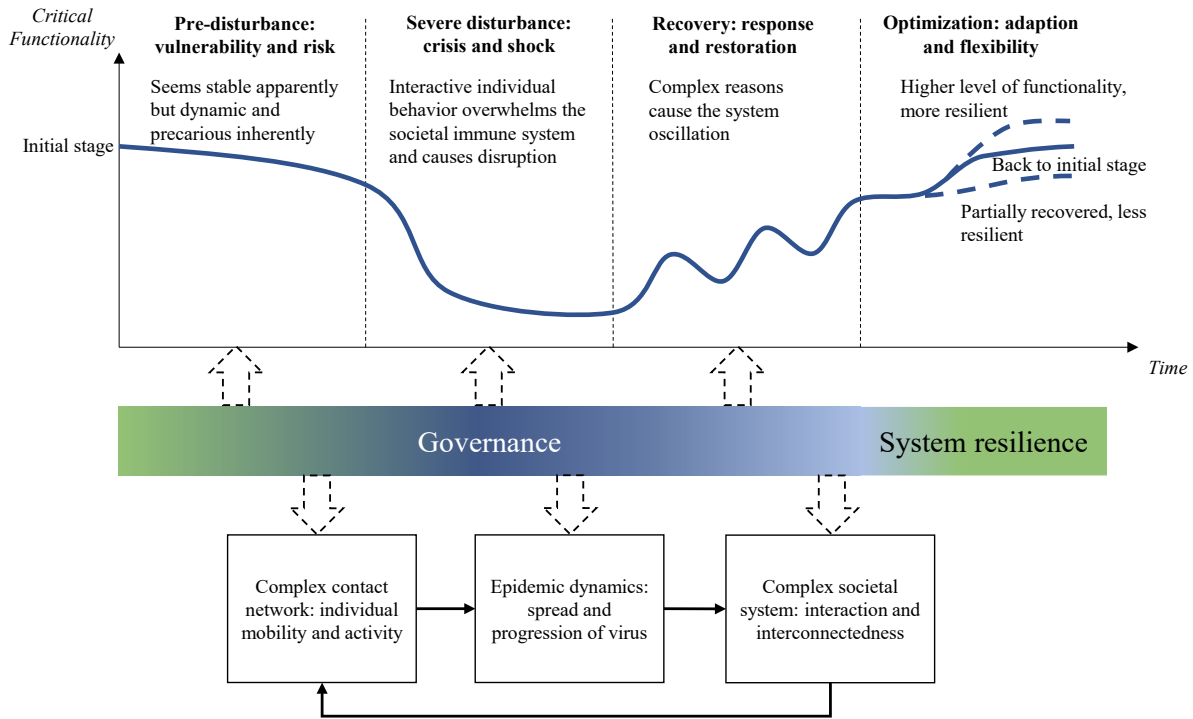


Figure 2. Resilience Framework under COVID-19 Crisis, Emphasizing Importance of Governance. (Green Bar Represents No/Less Policy Intervention, while Blue Bar Represents the Intense Policy Intervention)

Pre-disturbance Stage. In Figure 2, at the pre-disturbance stage, the societal system is still fully functional. If possible, system identification, preparation and absorption of the hazards should be started to be completed at this stage to minimize the risks and losses. However, this mission is nearly impossible for governance system at the early stage of the emergence of COVID-19 because it requires the risk to be precisely predictable and the interaction within the system must produce a linear result, which is contradicting to the property and fact of a complex system. In contrast, people may get baffled by some crowdsourcing information from social media or friends and overestimate or underestimate the dangers of the virus at the early stage. Policymakers may identify the risks and potential losses and start setting the corresponding prevention policies and creating the procedures to map out the responses to lessen the shock and negative effects on the societal system. Nevertheless, because the governance system will need a response and coordinating period to make and implement the policy, the system may not fully be prepared to absorb the hazards. Besides, the governance system may not fully understand the characteristics of the virus at the early stage, which will make the policymaking process even slower with time delay. Without much feasible and effective early-stage action, globalization and international activity may cause the virus to become pervasive. During the virus incubation period, the societal system appears to be stable, but the actual internal interactions act constantly and stochastically on the intra- and inter-system, causing dynamic and emerging risk.

Severe Disruption Stage. After the pre-disturbance period, the virus will widely spread on the scale-free network, where the “at source” control alone is not sufficient enough to restrain virus diffusion. That is, massive and interactive mobility system, inconsistent and opaque communica-

tion lead the surging cases, which overwhelms the societal immune system and causes the uncontrollable spread of the virus resulting in a severe disturbance. During this period, the governance system will play a critical role in the management and evolution of the epidemic. All the social resources should be shared, integrated, and prepared to prevent and contain the spread of the virus. As discussed above, the diversified and multisectoral policies from the temporal-spatial dimension intertwine with the people's behavior. When different containment policies take into effect, the societal system may respond actively and start to level off; otherwise, the system may keep lockdown for a long period and continuously dampen the system resilience and increase risks with possible threats and transmission. The different effectiveness and efficiency of various policies may affect the recovery process resulting in far-reaching effects.

Recovery Stage. Waiting until the outbreak is under control either due to the tiredness of susceptible people or the effect of the control measures or vaccination. The system will prepare to get into a restoration stage. During the restoration stage, uncertain factors such as climate change, human response, various delays, public concern and lifting of the interventions may influence individual behavior and cause dynamic and oscillation. Besides, the relaxing or uncertain implementations may trigger the rebound of the virus, such as France, which has declared a second national lockdown at the end of October 2020. The second and subsequent virus waves may also prompt fears and instability of the societal system resulting in oscillation and turbulence. Nevertheless, since the system already has the experience of responding to the crisis with already enhanced the positive and adaptive interaction and interrelationships between subsystems, it will gradually restore its origin functionality if the COVID-19 is under control. If the governance system doesn't perform competently or effectively enough, it may prolong the recovery process and eventually lose part of the resilience in the post-COVID-19 period.

Last Stage. In the last phase, the societal system and the subsystems may fully recover or partial recovery with a long-term plan. During this phase, the interconnectedness and interaction of systems may reconfigure the complex system to adapt to the new regular societal system. There is a possibility that the enhanced and integrated governance system may transform the societal system to cross thresholds into a new stage of trajectory, which partially depends on the outcome of governance system. On the one hand, a resilient system's "new normal phase" may be more adaptive and resilient than before with higher functionality with structural change at different levels. For instance, a more diversified education system will help us respond to future crises quickly to connect online and offline education seamlessly. And a more capable and strong public health system can anticipate and prepare for the next pandemic quickly. The lessons we learn from the experience may enhance the capacity of preparedness and systemic resilience too. On the other hand, it's possible that the societal system partially loses its function and becomes less resilient. When experiencing a severe disaster, the societal system is not capable to respond and adapt the shock brought by the pandemic. This may cause the system resilience to take a longer time to be recovered or even permanently dampened in some of functions. In other words, when dealing with recurrent shock, the societal system does not have enough built-in redundancy and adaptive capacities to maintain sustainability, such losses including human death, irreversible damage to human wellbeing or social assets, or even the system crash, etc.

Therefore, the governance system exists throughout the entire process. When the society system encounters disasters such as COVID-19, the governance system and system resilience, with the sharing goal of flexibility, diversification and adaptivity, continue to maintain systemic functions

and change human behavior through nonpharmaceutical policy. In the meantime, as an inherent property of the complex societal system, resilience also measures the stability and functionality of the entire society across different periods.

Deepening the Assessment: Finding the Dynamic, Causal and Complex Feedback Mechanisms in the Complex Societal System

Model Development

In system thinking field, causal loop diagram (CLD) allows a more comprehensive and dynamic causal understanding of the complex system by highlighting the interactions, causalities and interrelationships with multiple feedback loops. These cause-effect loops provide an efficient approach to explore the complex societal system with feedback mechanisms, delays and interconnection to support the complex and interactive policymaking process (Sahin et al. 2020). The causal loop diagram is developed by gathered information and knowledge that is accomplished from the latest research outcomes, published papers, the government-authorized website and some empirical studies. Because our understanding of the COVID-19 is still limited, this is not an exhaustive solution but strives to achieve a collective causal loop diagram linked to intervention policies in order to provide stakeholders a deep insight into how to reduce unfavorable outcomes and create a resilient system.

Crisis brings challenges and opportunities together to the whole system, which partly depends on the choice and effect of the governance system. In the current complex situation under the risk of COVID-19, each component of the complex societal system affects others, which are deeply interlinked with the emergence and spread of the virus. And individual behavior, as the essential component of complex system, will be significantly affected by the governance system. Based on this, we leverage human behavior change as a breakthrough point to develop this CLD model, which is also built upon the classical epidemiology model: Susceptible-Infectious-Recovery (SIR) model, where the total population is the sum of Susceptible, Infection, and Recovery people (Korobeinikov & Maini 2005). Our CLD is focused on the interactions among control policy, individual behavior change, and societal structure towards system resilience presented in Figure 3. Based on the current situation, we assume and hope not everyone in the system will be infected or get antibodies. So we add another variable: “Number of vulnerable people” into the system displayed by the red arrows in the CLD. The sum of vulnerable people, infectious people, recovered people is smaller than the total population simply because some people will not get infected. Those who do not get infected or don’t have antibodies are targeted by the implemented policy to prevent them from the virus. Besides the policy intervention, these people’s behavior will also change according to the severity of the pandemic through psychological factors such as generating the fear for the current situation or self-protection by reducing public activities. The red reinforcing feedback loop shown in Figure 3 represents the exponential growth of infected cases with little or without any policy interference or behavior change at the early stage.

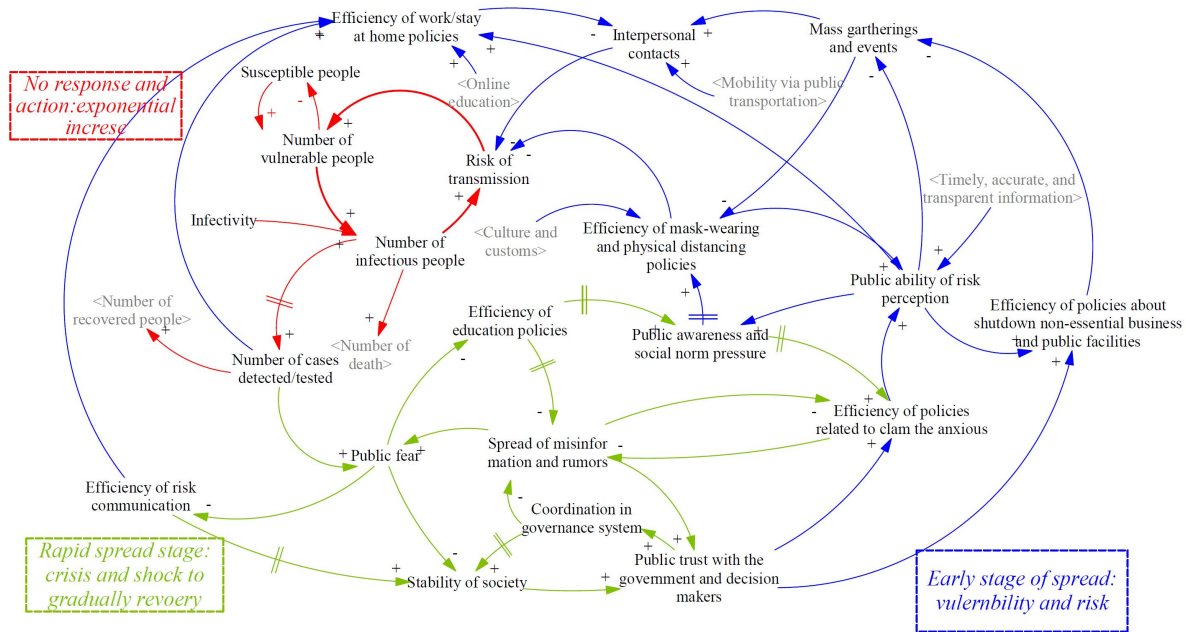


Figure 3. A Causal Loop Diagram Linked to Governance System in Complex Societal System with Three Resilience Stages

Visualize the Complexity and Interaction via Feedback Loops

In order to control the newly infected cases and reduce the peak during the pandemic, intervention policies are critical to extenuate the damage caused by the pandemic and restore the system resilience. The response of the governance system should not only deal with the current description but also consider the long-term issue with sustainability. The effectiveness of a policy can be roughly evaluated by the newly infected cases after the policy implementation after a certain time, while the severity of the pandemic will, in turn, affect the intensity and diversity of the new policy. Figure 3 includes the most common policies currently implemented in the context of human behavior change under the governance system, such as mask-wearing and social distancing policy, the shutdown of non-essential business policy, prohibit mass gathering and events policy, etc.

Because of the information asymmetry and the sign of exponential daily increase at the early stage of the pandemic, in combination with other psychological factors, rumor and misinformation may lead to panic. Prompt, credible, accurate, and transparent risk communication should be established between the public and authorities to enable people at risk to make informed decisions to protect themselves from rumors and misinformation. Individuals' responses highly affect the prevention of transmission even ahead of the implementation of policies. Through the internet and the local community, the governance system creates pressure and incentives reducing the spread of rumors and strengthening people's awareness of self-protection (Legido-Quigley et al. 2020). From this perspective, the importance of education policy needs to be highlighted. It can deliver timely and transparent information through different channels, eliminate the impact of misinformation and thus reduce the public anxiety. The educated and calmed people may reestablish their capability to judge the information and screen the useful information. Accordingly, at the beginning stage of the pandemic, most policymaking process requires preparation period. And the

evolving of the virus is still under observation. Governance system should pay attention to refute rumors, maintain the social stability and enhance the credibility displayed by the green arrows of Figure 3. At this stage, the system may remain most of the functionality, where all the policy implemented is intended to improve the system resilience to minimize the pandemic impact on the societal system.

During the rapid spread stage of the pandemics with severe disturbance of the whole system, it is crucial that people shift their behavior to slow down the spreading, especially the restriction movement and self-protective behavior. For example, some of the regions mandate mask-wearing at the public and practicing social distancing to eliminate the risk of possible transmission directly. The effectiveness of the mask-wearing policy is closely related to the message people received from the public. That is, if most people approve of the actions of wearing a mask, those who don't wear masks may be disciplined by the social norm and start to wear it by consciousness raising (Bavel et al. 2020). The behaviors changed by education policies and by social norms from community pressure will also improve the awareness of self-protective presented by blue arrows in the CLD. Moreover, the improvement of risk perception ability may connect with public awareness to affect policy implementation. Risk perception is the subjective judgment, based on an individual's values, beliefs, attitudes, and culture, that people make about the attributes and seriousness of the risk. Another way of utilizing the social norm and self-protective awareness falls into relieving the public anxiety: enhance the ability of the individual's risk perception, in turn, further standardize the social norm. In this stage, most non-essential business and public facilities are temporarily closed due to the policy requirement of social distancing, which may have an immediate negative impact on the local economy. However, the policy directly reduced the possibility of mass gatherings and events. The mass gathering will increase interpersonal contact, dampen the effectiveness of mask-wearing and social distancing policy, and even cause the super-spreading events. On the other hand, the risk perception, a capacity to identify the potential risk based on the real-time communication of the severity of the pandemic, will significantly increase if there is a comprehensive scientific understanding about potential health effects via social media and technology. At the rapid spread stage, the governance system should consider both behavior change, which has an amplification effect in the community, and mandatory policy concerns to reduce mass gathering and cut off the spread channel displayed by the blue arrows. In this process, the societal system is suffering from the crisis and shock, causing the disruption, where the governance system is responsible for lessening the functional loss by utilizing the interconnection between different policies for stakeholders. When the interaction and interconnectedness continue to respond to the crisis and take effect, the societal system may gradually restore some functionality.

Attentions on Time Delays

The time delay of the policymaking, implementation and behavior change cannot be ignored in the societal system under the crisis. It consumes time to develop policies, and some of the policies will not become very effective immediately after implementation because of the behavioral inertia. Moreover, since the virus has an incubation period, the delay also exists from infections to symptoms or infectious, and from symptoms to test. Some of the asymptomatic carriers make the prevention of COVID-19 more different and uncertain. Furthermore, time delay in governance system will also affect the stability of the whole system, where the delay may be derived by the shortage of the correct and latest information about the virus, the less coordination of in-

ter-governance system and the misestimate of the current status of the whole system, etc. Another vital factor is individual behavior. It takes time to improve people's awareness and risk perception capability and subsequently affect their behavior. The time delay will add a step to the complexity of the societal system, and in turn, make the governance system more dynamic and unpredictable. Although the delay is inevitable, we may have an effort to shorten the delay by maximum the advantage of diversified technology and policy to restore system resilience as much as possible.

Conclusion and Future Work

The COVID-19 crisis has a nexus impact on the whole society. Although the future will always be unforeseeable and challenging, the rebound and development of our societal system will continue shaped by this crisis. In this paper, we leverage the systems approach to define the societal system as an adaptive and complex system with an integration of human activity, governance system together, focusing on the accomplishment of system resilience. And we provide a holistic analysis of governance system, human behavior and system resilience, as the inherent system properties played a critical role in the whole society. Moreover, we systematically examine the multi-stage system resilience corresponding to the human behavior change with the effort of different governance actions with the utility of a resilience framework under the background of the COVID-19 propagation. Finally, to deepen the study, we propose a causal loop diagram to understand the current crisis and challenges with dynamic interaction and interconnectedness in the societal system under time effect. Upon this study, we hope to provide a systems viewpoint to the policymakers and stakeholders about how to establish a resilient system to sufficiently prepare for the subsequent hazards for the whole societal system with the objective of minimizing the function loss in the early stage of the crisis and shock timely and cost-efficiently, and additionally, offers guides of restoring a holistic resilience society with opening up the uncertainty and unruliness in this dynamic and non-linear world. Systems approach provides a better understanding of behavior change for the complex system and visualizes interactions of policy interventions linked to system resilience. And, therefore, recognize the intrinsic complexity and transform the society to a more resilient aggregation for meeting future crises.

The future work should focus on the validation of the system dynamics model by simulation approaches such as agent-based model to test the interaction and impact between governance system and human behavior in the societal system from multiple dimensions. Agent-based model designed for infectious diseases such as COVID-19 can consider different demographic characteristics and social contact networks that allow governance system to manage various interventions at temporal-spatial dimensions. A way forward, by visualizing and quantifying the complex and dynamic change linked with resilience, we want to provide an insight about how to evaluate the policy combinations and test the complex interactions in several scenarios and phases by the real-world data.

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