# A Multi-dimensional Analysis to Societal Resilience in Context of COVID-19: A Systems Thinking Approach

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***Abstract*—The COVID-19 pandemic has highlighted the importance of system resilience in confronting major crises. This paper leverages the systems thinking approach to emphasize the interactions and feedback among systems for fostering resilience from multiple levels and timing stages. This paper also emphasizes the impact of socio-technical systems on societal resilience, since it is a crucial aspect of resilience and is discussed in terms of its ability to disseminate information, policies, and promote system resourcefulness and flexibility. In addition, we analyze the interrelationships and interactions among systems at multiple levels, including macro-level (society), meso-level (community and local network), and micro-level (individual and families), to foster resilience from different angles. We also review policies that correspond to different spatial-temporal resilience stages (preparation, disturbance, recovery, transformation) to provide enlightenment for policymaking from a resilience thinking perspective. Our analysis reveals that a system's resilience relies on the interconnectedness and feedback mechanism among systems, and policy design should aim to minimize functionality loss in the shortest time to maintain robustness and rapidity in response. Additionally, the dynamic and unpredictable nature of the transformation process should be taken into account when implementing policies at different levels. Our study can serve as a future research path aiming at enhancing societal resilience in facing the challenges and preparing for potential pandemics in the future.**

***Keywords- resilience; systems thinking; complex system; COVID-19; healthcare system; governance system; socio-technical system.***

## I. INTRODUCTION

The COVID-19 has triggered a global systemic crisis that reveals the vulnerability, fragility and uncertainty of the societal system at the beginning of the pandemic. While the end of the pandemic may be in sight, its variants will likely continue to coexist with society for a long time [1][2]. As we continue to study COVID-19, it has become clear the pandemic is not just a public health problem, but a social problem that requires effort from every aspect of the societal system to respond to the crisis. In this paper, we will discuss how to deal with COVID-19 and recover societal resilience from a systems thinking viewpoint in both the current and post-pandemic era.

The outbreak of the COVID-19 pandemic and the resulting systemic crisis have affected almost everyone [3][4]. Given that we cannot avoid all risks, a new subject arises: what can be done to minimize disruption and damage, and restore social order with adaptivity, diversity, and stability? Severe disruptions like these prompt us to consider how we handle interruptions, withstand threats, and adapt to adverse situations in the future, at different levels. As a result, the concept of "resilience" has received considerable attention in the context of COVID-19 and the complex systems approach. The term "resilience" derives from the Latin word meaning "bounce back" [6], and it was initially used in ecosystems to enhance stability and sustainability by conserving biodiversity [1][7].

In recent years, resilience has been well developed and adapted to different societal system sectors such as socio-ecology, socio-economic, socio-technology, and socio-science [8]. In broad terms, system resilience refers to the ability of a complex system to return to pre-existing equilibrium better, with redundancy, after experiencing a crisis. It involves the capacity of individuals, families, or even the whole society to prepare, respond, absorb, adapt, and minimize the negative impact of the crisis [9][10]. For complex adaptive systems, resilience can be seen as the inherent property of the system [2] that represents a process by which complex systems absorb negative impacts from stress and disruption and improve functionality properly. Importantly, system resilience is not a transient state that causes deviation in functioning or behavior. Rather, it is a process by which a system can cope with disruption and adapt from crisis to transformation [11]. By understanding resilience in this way, we can better prepare and respond to crises like COVID-19, and ultimately, enhance the resilience of our societal systems.

The rest of the paper is structured as follows. In section II, this study employs a systems thinking approach to analyze interactions and feedback among systems in addressing the COVID-19 pandemic to get a holistic understanding of systemic resilience. Section III emphasizes the role of socio-technical systems in societal resilience. In section IV, we examine interrelationships at macro, meso, and micro levels, and explore how these interactions impact resilience across different stages and sectors. In section V, our research then reviews policies for various spatial-

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temporal resilience stages, offering insights for policy development and enhancing societal resilience against future pandemics. The conclusions close the article. By utilizing systems thinking, we facilitate scalable and appropriate policy implementation in decision-making processes, incorporating dynamic and feedback control. Our study contributes to current resilience research in complex system sectors, aiming to tackle crises effectively.

## II. COMPLEXITY OF SYSTEMIC RESILIENCE

### A. *Resilience: More Than a Single System Feature*

The complex societal system implies that the world changes non-linearly and is composed of massively interconnected systems and networks [14]. The continued evolution of resilience originates from the interaction and interdependency of systems and environments [15][16]. Dynamic relationships are challenging to identify [17], whereas linearity usually cannot be used to describe interconnections and interactions within systems or to reflect the emergent properties of the complex societal system [3], [4]. Thus, we must re-examine the importance of resilience in complex systems, especially given the ongoing impact of the COVID-19 and its variants. Overlooking the interconnectedness of resilience between systems will significantly increase the vulnerabilities of a systemic shock [5].

While enhancing and developing system integration has led to closely paired systems that improve efficiency and effectiveness in normal conditions [18], advanced technologies applied in continuously evolving systems with tight connections may result in negative effects being mapped onto other systems and causing a disruption of balance and normalcy [19]. Our tendency to target the most apparent problems without considering broader implications can lead to unforeseen consequences. For instance, the implementation of strict policies may overlook the complexity and interaction of the global economy and transportation, resulting in the creation of new social problems that accumulate over time [2].

### B. *Resilience: Facing The Interactions and Collectivity in The Dynamic World*

Moreover, even the resilience reflected in a single system may manifest in different ways, both within and beyond the system [20]. For example, the resilience of the healthcare system usually interweaves with the economic system, supply chain system, governance system and other related systems. A typical phenomenon is that during the early period of the pandemic, the healthcare system is not functioning properly due to the shortage of supplies, which is highly reliant on the supply chain and transportation system. At the same time, the supply chain and transportation system are highly dependent on the labor force, which increases the chance of massive transmission if they go back to work too soon, increasing the complexity of policymaking and pressure on the healthcare system [21]. System complexity can prompt societal development, but it can also cascade adverse effects, leading to system failure counterintuitively. Thus, it is essential to consider the interconnectedness of different systems in developing and implementing resilient policies.

Considering the close intertwined problems from a complex systems viewpoint, society can be understood as a whole but structured into different systems based on societal elements and related factors and subsystems, such as the governance system, epidemiological factors, human activity, healthcare system, socio-technical system, and infrastructure system [4][20][22]. Multi-systems and factors of society are involved at various scales, as shown in Figure 1. In such a

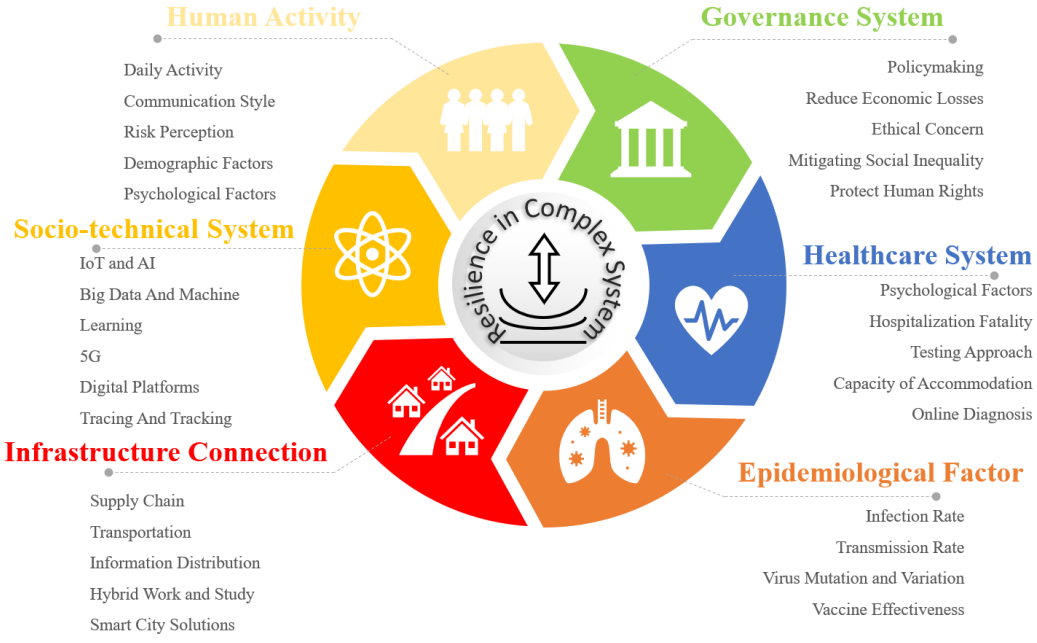


Figure 1. The interconnections and interactions in Complex societal system resilience facing to COVID-19

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complex societal system, system resilience is driven by both positive and negative outcomes, such as sudden changes or crises and the adaptation of new features, which can shape the complex system and impact resilience at different sectors and levels [15][22].

## III. The Role of Socio-technical System Resilience under COVID-19

### A. *Socio-technical System Aligned with the Concept of Society 5.0*

The COVID-19 is different from previous global crises because it happened after the integration of human-technology interactions at the organizational or societal level. [17]. Therefore, we emphasize the role of the socio-technical system in systemic resilience, which indirectly affects the virus spread through information dissemination, policy implementation, and behavior change. The socio-technical system can be identified as the combination of human-centered systems and technological systems [18]. Currently, the socio-technical system can be viewed as a complex system formed by the fusion of virtual and physical elements and components interacting with subsystems in society such as education, transportation, and healthcare system in society, affecting people's daily life and decision-making process for stakeholders [10][19].

The concept of Society 5.0 integrates society, human factors, and technology within a broader perspective, emphasizing the interrelatedness of functionalities within the societal system [19]. With the shift to Society 5.0, the socio-technical system has become increasingly significant for ensuring system resilience, particularly for identifying and addressing heterogeneous threats. The socio-technical system is embedded within the societal system and interacts with multifaceted systems to make flexible and adaptive decisions, ensuring cohesion and resilience in fast-changing environments. The hyper-connectivity and communicability of different systems in the complex societal network allow them to be cascaded like nodes in a network, creating feedback loops characterized by interdependent and communicative systems, which serve as an essential layer to support system resilience.

### B. *The Impact of Socio-technical System on Systemic Resilience*

On the one hand, the maturity of the infrastructure system, a result of globalization and urbanization, has accelerated the spread of the virus and negatively impacted societal resilience due to insufficient preparation and policy implementation at the beginning of the pandemic [1]. However, advances in socio-technology have also facilitated the dissemination of information and policies, changing hu-

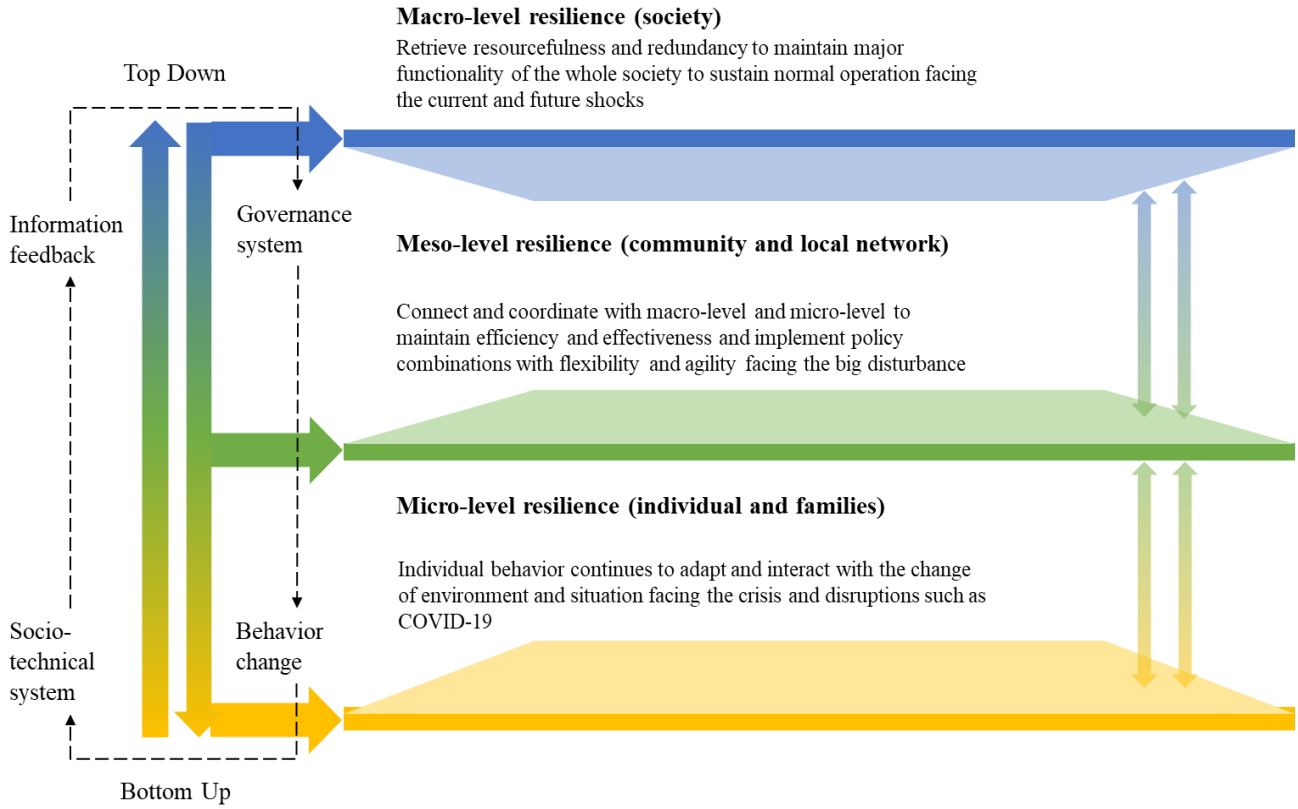


Figure 2. A hierarchical schematic representation of systemic resilience

man behavior and awareness of the current COVID-19 and future crises [19]. The socio-technical system, by involving itself in every stage of the resilience process, promotes system resourcefulness and flexibility to solve difficulties.

On the other hand, technology has played a crucial role in enhancing resilience at individual and systemic levels by enabling innovative risk mitigation methods. For example, increased online connectivity reduces physical encounters, minimizing transmission risk while maintaining daily routines through telemedicine, online education, and remote work [1][3]. Although COVID-19 may temporarily hinder development plans, the long-term outlook remains optimistic, as the crisis drives the creation of more intelligent and resilient societal systems. The socio-technical system improves risk estimation, prediction, communication efficiency, and risk perception abilities, allowing for better understanding of interactions and delays within and among systems.

## IV. IDENTIFICATION OF MULTI-LEVEL RESILIENCE FACE COVID-19 PANDEMIC

To gain a deeper understanding of system resilience, we conduct an integrated multi-level analysis, including macro-, meso-, and micro-levels, to visualize the interrelationships and interconnectedness among systems when facing major disasters, as shown in Figure 2 (developed based on [1][4] [15][23]). This collaborative effort is necessary, as the actions taken in one system can have an impact on others in a complex adaptive system. In this section, we aim to illustrate perceived risk, vulnerability, and societal reactions, as well as to discuss the interaction and interconnectedness that cascade across different levels, based on the principles of systems thinking.

### *A. Macro-level Resilience*

Macro-level resilience assesses overall system resilience while focusing on the complex interconnected factors that shape the systems' ability to adjust and adapt to traumatic events. During emergencies, macro-level resilience takes the entire society into consideration, performing the function of retrieving resources and redundancy to maintain the major functionality of the whole society and sustain society's major functionalities in the face of current and future shocks [4]. Since the macro layer has access to collect and allocate most resources including information and entities, strategic accumulation retrieves resourcefulness will continually nourish the whole system to have redundancy in crisis management. The governance system intervenes from the top down to guide the meso-level to formulate more flexible and appropriate policies and turn people's behavior towards a healthier and more resilient direction to recover from emergencies. These effects influence the design and implementation of future policies aimed at building a sufficient buffer for any national emergencies. This feedback may be positive or negative due to the various system interactions and interdependencies. Therefore, the macro layer provides a framework to guide the sustainability and resilience of different systems to maximize the well-being of the entire society in the midst of an epidemic.

### *B. Meso-level Resilience*

The meso-level of the resilience system serves as a vital connection between macro and micro levels, representing local organizations and communities with some autonomy. This level acts as a strong adhesive and moderator between society and individuals [24]. Policymaking and implementation can be time-consuming, and macro-level restrictions may not immediately restore societal resilience, making meso-level flexibility crucial for policy implementation. In response, the meso-level governance system can adapt to local conditions, targeting operational robustness and agility to improve resilience for future pandemic waves. It cannot be overlooked that a single failure or debilitation in one system, or a negative interaction between systems, can impair systemic resilience from the operational level to the individual level [17]. Resilience at the micro level may emerge from the bottom-up, affecting the ability to absorb and adapt to threats at meso and macro levels. Detailed and flexible governance enables communities and organizations to interpret and implement policies based on their situation, promoting local resilience and ultimately enhancing the entire social system's resilience with the socio-technical system's power to deliver information and receive feedback.

### *C. Micro-level Resilience*

In addition to the collective approach to systemic resilience, individual views and perceptions are also crucial in navigating the complexities of the world. The importance of individual and family-level resilience cannot be ignored as they represent the basic and vulnerable units of society [1]. The COVID-19 pandemic has had a significant impact on the mental health and well-being of individuals, exposing their vulnerability and substantial risk. Extended self-quarantine, canceled social events, and social distancing have all significantly affected human well-being [24]. During the early stages of the outbreak, widespread rumors caused by fear of the unknown also had a detrimental effect on mental health [16].

Individual behavior rapidly adapts and interacts with changes in the environment and situation based on the information and guidance provided by the macro-level and meso-level of society. The socio-technical system collects reactions from individuals and provides feedback to the governance system for policy adjustments and improvements, promoting resilience from every aspect of society [19]. Furthermore, individuals may overcome disturbances and adapt their behavior to the changing environment in the post-pandemic era through the benefits of human-centered design. Matured socio-technical systems have created various interaction mechanisms and opportunities to cultivate resilience in individuals.

## V. DEEPER THE ANALYSIS: A RESILIENCE MATRIX

COVID-19 unlike discrete events such as tornadoes or earthquakes, has lasted for years with massive and multifaceted interactions among systems. It should be recognized as a complex process within time constraints to

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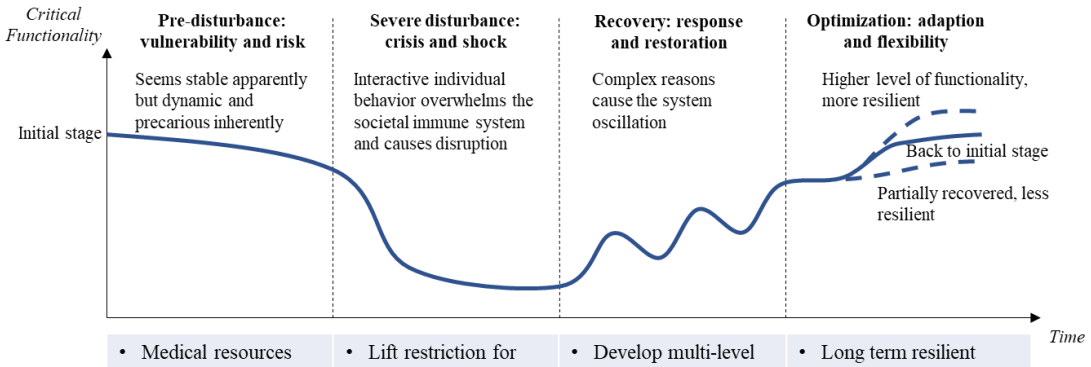


| | Pre-disturbance: vulnerability and risk | Severe disturbance: crisis and shock | Recovery: response and restoration | Optimization: adaption and flexibility |
|---|---|---|---|---|
| **Macro-level resilience** | • Medical resources reservation<br>• Impact planning and analysis<br>• Healthcare demand estimation<br>• Response planning<br>• See the big picture<br>• Media publication<br>• Public Engagement | • Lift restriction for healthcare<br>• Evidenced decision making<br>• Leverage the power of socio-technical system<br>• Resources distribution<br>• Shorten resolution process during emergency | • Develop multi-level recovery framework<br>• Flexibility in policymaking<br>• Facilitate the business continuity<br>• Enhance public credibility<br>• Support for reopening | • Long term resilient plan<br>• Review and improve related policies<br>• Develop stimulus package<br>• Develop strategies for new waves of disaster<br>• Long-term consideration for society sustainability |
| **Meso-level resilience** | • Develop communication channels<br>• Public education<br>• Medication distribution<br>• Information sharing<br>• Essential items restriction<br>• Dispel rumors | • Strong collaboration to connect each layer<br>• Coordinate health facilities, transportation and other sectors<br>• Set up vaccine sites<br>• Prevent large population gathering | • Provide mental health support<br>• Flexibility in policy execution<br>• Monitor and support local vulnerable population<br>• Implementation of recovery framework | • Strengthen community capacity for continues local support<br>• Continue operating key testing site and shelter<br>• Monitor and report the potential new wave of disaster<br>• Psychological health counseling |
| **Micro-level resilience** | • Living resources planning<br>• Self-education<br>• Emotional preparation<br>• Maintain good communication with local governance system<br>• Risk perception | • Keep social distance<br>• Increase virtual communications<br>• Volunteer and community support<br>• Protect yourself and families<br>• Online education and work from home | • Preparing for back to work and school<br>• Continue personal safety protocol<br>• Request support for both health and financial difficulties<br>• Psychological adjustment | • Continues recovery of normal life<br>• Caution for potential new wave of disaster<br>• Build new resilience and Learn from disasters<br>• Maintain flexibility and adaptability |

Figure 3. Resilience and policymaking matrix during COVID-19 pandemic at different stages

absorb negative impacts and gradually restore functionalities with some newly emergent properties to adapt to changes. Various policy combinations can affect resilience at different levels and degrees, resulting from interactions across different scales of social structure and levels of governance [15]. An accountable and reliable governance system can minimize the impacts of the pandemic. Inspired by the classic resilience curve [2]–[4], this study reviews and outlines implemented policies for different resilience stages (preparation, disturbance, recovery, transformation) across macro-, meso- and micro-levels based on current research on resilience and governance to respond to disturbances and traumatic events, as shown in Figure 3 [3][14][19][20][22][25]. Examining policy implementations from both spatial-temporal dimensions can help stakeholders govern the uncertainty and dynamics in a complex world. The resilience matrix integrates a range of policies across domains such as education, transportation, technology, demographics, healthcare, and social norms related to society, community, and individual resilience change.

Policymaking at different levels must take into account various time stages, not only focusing on immediate policies for immediate results, but also considering long-term resilience. The system must accumulate enough adaptability and robustness to respond to continuous turmoil, and have redundancy and resourcefulness to prevent significant functionality loss. The constant intertwining of systems combined with policymaking also makes the transformation process unpredictable. The system may bounce back to the pre-disaster stage with the initial equilibrium, or it may become more resilient to transformation with higher levels of functionality and creativity. However, some systems may fail to recover or require a long time to restore the function [2][25]. Thus, in the post-pandemic era, opportunities and crises will coexist, and policymakers must balance short-term and long-term considerations to promote resilience at all levels.

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## VI. CONCLUSION

In conclusion, this paper highlights the importance of system resilience in disaster management and risk response, using a systems thinking approach to examine multi-level interactions and feedback. By focusing on system interdependencies, we can better identify vulnerabilities and strengths, informing policy for various spatial-temporal resilience stages. Our study aims to promote cross-sectional contributions, enhance societal resilience, and minimize functionality loss during crises, such as the COVID-19 pandemic.

However, our paper does have some limitations, as we could not include detailed case studies to better explain our findings due to space limitations. For future research, we suggest exploring the impact of different policy combinations on resilience across various stages through evidence-based studies. As the COVID-19 pandemic offers a unique opportunity to assess system resilience performance, it provides insights for preparing for future crises.

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