Resilience to the COVID-19 Pandemic: A Distributed Situation Awareness Perspective

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***Abstract* — Provisionary command centers for containing disease outbreaks can be an effective strategy in coordinating efforts by different government ministries and agencies to provide resilience that limits human and economic losses. This paper applies the Distributed Situation Awareness (DSA) framework to investigate the fundamental design and operational principles of provisionary command centers that contribute to the resilience against disease outbreaks. The investigation involves a case study on modeling the DSA of the Taiwan Central Epidemic Command Center (CECC) that coordinates multiple government ministries and agencies to contain COVID-19. Task, knowledge, and social networks were developed and combined into one DSA network model to depict how the CECC operations in processing and distributing information enhance situation awareness (SA) of all the government agencies and citizens for a coordinated response to the pandemic. The DSA network model illustrates an interorganizational system architecture that can enable graceful extensibility of various government functions and sustained adaptability of the agencies against disease outbreaks.**

Keywords—Pandemic management, Distributed Situation Awareness, COVID-19, command center.

I. INTRODUCTION

The impact of disease outbreaks in past decades calls for global and local preparation to mitigate future loss of human lives and damages to the economy. Previous outbreaks such as SARS have costed the global economy more than $50 billion whereas the annual cost of moderate to severe pandemics is estimated to be $570 billion [1]. Presently, the COVID-19 pandemic has taken more than 500 thousand lives [2] and costed the world economy more than $8 trillion [3] as of July, 2020. The preparation and crisis management at the global level is clearly inadequate in the face of major disease outbreaks.

In the absence of vaccines, controlling the spread of COVID-19 is essentially limited to hygienic practices of social distancing, face covering, isolation/quarantines, and contact tracing [4], [5]. Surprisingly, the few available controls over COVID-19 did not translate to a similar level of human and economic losses across countries, even when restricted to developed ones. In other words, the containment response varied across the world resulting in significantly different outcomes. For example, when the discovery of COVID-19 was announced in Italy, the initial response was met with skepticism across the government and public even though several scientists had been warning for a potential crisis [6]. As a result, public precaution was limited and the government did not accrue the resources (e.g., Personal Protective Equipment, PPE) required to limit the spread of the virus, subsequently challenging the delivery of treatment to COVID-19 patients. The lack of interorganizational preparedness and tardy response to the pandemic across Italian government agencies also made contact tracing and containing the virus practically impossible, resulting in a series of wholesale restriction decrees [6]. Consequently, Italy suffered high death tolls and economic losses. In contrast, Singapore reacted early to COVID-19 by mobilizing a task force of multiple governmental agencies to coordinate interventions thereby limiting the spread of the outbreak [7]. Initial intervention included contact tracing effort between the Ministry of Health and the Police Force to identify links between individuals confirmed COVID-19 positive and their contacts. Singapore acted in a way that limited the spread of the outbreak and minimized the disruption to their economy.

Taiwan presents one of the most successful responses to COVID-19 despite the speculation that the country could have the second highest number of cases due to proximity and number of flights between China [8]. However, the experience with the SARS epidemic in 2013 cautioned the Taiwanese government to prepare for future outbreaks. As soon as the emergence of an infectious disease from China was known, the Taiwanese Center for Disease Control (TCDC) activated the Central Epidemic Command Center (CECC), which coordinates pertinent government ministries and agencies to control the disease outbreak. The CECC has helped Taiwan, the 17th most populated country in the world [9], to contain the outbreak at an early stage, resulting in only 447 confirmed cases and 7 deaths as of July 2020 [10]. Despite the partial border closure and delayed school openings and elections, Taiwan never instituted a full lockdown for COVID-19 [11]. The CECC also implemented contact tracing on infected individuals for isolation that has helped contain COVID-19 and prevent economic losses.

The CECC has been considered to be a major contributor to Taiwan's remarkable resilience to COVID-19. In particular, Taiwan shows that a provisionary command center can reorganize essential government services quickly to eliminate the effect of COVID-19 on the society. Due to early testing and screening, border restrictions, and integrating health data with travel records, Taiwan managed to avoid the lockdown and keep infected people quarantined [9]. As a result, Taiwan kept its economy running and citizens working while the schools only closed for two weeks after the winter break. Taiwan took these two weeks of school closer to disinfect schools, distribute medical supplies, regulate social distancing guidelines inside

schools, and implement procedures for schools with COVID-19 cases before schools open [12]. The swift and collective response facilitated by the CECC results in the resilience that enables Taiwan to return to relative normalcy in the face of a surprised pandemic.

The effectiveness of the CECC in Taiwan illustrates that provisionary command centers can enact quick, coordinated response across government agencies [13], [14] required for resilience against infectious diseases such as COVID-19 [15]–[19]. Thus, recent publications have provided operational descriptions of the CECC for others to consider for developing a response to COVID-19 [12], [20]–[22]. However, research has not focused on investigating the fundamental or theoretical design and operational principles of how the CECC or similar command centers contribute to the resilience against infectious disease in general. A fundamental investigation into the CECC could provide the engineering knowledge invaluable for generalizing how to make preparations for utilizing provisionary command centers for future disease outbreak management or even other disaster response.

One central function of such provisionary command center like the CECC appears to be enabling communication of critical information that different government agencies do not gather or need during routine operations. For example, through the CECC coordination, Immigration and Customs not only quickly restricts and quarantines travelers deemed high threats to public health according to TCDC and the Ministry of Health, but also collects critical data for the TCDC and the Ministry of Health for an accurate and up-to-date assessment of the COVID-19 situation in the country. A lack of awareness about disease control requirements at the border could permit infected travelers to start community spread. A lack of awareness of incoming cases could result in a policy of opening the economy too soon or late. Also, the involved government agencies appear highly specialized in providing specific information, such as medical expertise in quarantine guidelines at the TCDC and operational expertise in collecting traveler information at the Immigration and Customs. As mentioned, many different activities are involved in COVID-19 control, so the CECC must be facilitating a high level of communication across many specialized government agencies to achieve the remarkable epidemic control outcomes.

Distributed Situation Awareness (DSA; [23]) appears to be a suitable framework for studying the operations of CECC, or generally, the fundamental design of effective provisionary command center for epidemic management. DSA is defined as 'the activated knowledge for a specific task and a specific time within the system' [23] driven by the exchange of information and specific situation within the system. The distinction of DSA to other situation awareness (SA) theories is the focus on information transaction and distribution amongst human and non-human agents, rather than how individuals assess the situation [24]. That is, DSA focuses on how SA is distributed and transacted among human and non-human agents. As exemplified by the CECC, epidemic management requires many specialized government agencies to gather, process, and transmit information to maintain the SA of one another as no single agency could acquire or possess all information about the epidemic in a country. Thus, outbreak management is an emergent property of SA distribution and transaction that is encapsulated in the DSA framework. Thus, DSA is suitable for analyzing COVID-19 management by the CECC.

This article presents an investigation into the CECC operations adopting the DSA framework to illustrate how a provisionary command center can provide the temporary communication channels and resources to acquire and distribute SA that would enable various government ministries and agencies to redirect their resources for adaptive and graceful extension of their functionalities. The remainder of this article is organized as follows. Section II describes the DSA modeling method adopted to study the CECC in facilitating transactions of SA in the Taiwanese government and Section III presents the DSA network model of the CECC. Section IV discusses how provisionary command centers can provide resilience during a crisis as suggested by the CECC DSA network model.

II. METHOD

The three-part method prescribed by [23] was adopted to model the DSA of the CECC as a case study of provisionary command center in facilitating communication and coordination for disease outbreak that would otherwise be unavailable during routine operations. This section further describes the CECC, followed by methodological details of the DSA and the three-part modeling method adopted in this investigation.

A. Central Epidemic Command Center (CECC)

The Taiwanese government designs the CECC [25] with a dynamic structure for responding to infectious disease outbreaks [21] because each outbreak might require different treatment, transmission, control measures, etc. For COVID-19, The CECC organization structure consists of representatives from different ministries and agencies to run logistics, operations, and intelligence to contain the outbreak [21], [26]. The logistics section is responsible for resource coordination, research and development, information management, administration, and public information. The operations section is responsible for border quarantine, community epidemic transmission control, and healthcare emergency response. The intelligence section is responsible for surveillance and tracing. The CECC works under the commands of Dr. Chen Shih-Chung, an epidemiologist, and Chen Tsung-Yen, the Deputy Minister of Interior. The management of the CECC assesses the outbreak situation and determine the involvement of various ministries and agencies in the CECC for managing the outbreak.

B. DSA modelling methodology

DSA models can describe *who, how,* and *what* in CECC operations central to controlling COVID-19. Amongst other applications (e.g., [27]), DSA modeling has successfully illustrated the social/who, task/how, and knowledge/what element of a command center for patient flow management, thereby highlighting its strengths and weaknesses in the communication and coordination [27]. Thus, DSA model of the CECC outlining the social, task, and knowledge elements in

managing the epidemic should provide insights into effective design of provisionary command center. Specifically, the DSA model would illustrate useful links between different government agencies and the SA acquired and disseminated necessary for coordination and decision making for the epidemic.

The DSA three-parts method of data elicitation, extraction, and representation [23], [27] was applied to model the CECC operations to illustrate its role in containing the COVID-19 outbreak in Taiwan. The DSA three-part method helped to identify functions and knowledge/SA of the CECC as well as the government ministries and agencies pertinent in their communication. Due to the lack of access to the CECC, data elicitation only involved documentation review of published articles and public video recordings rather than internal documentation review, interviews, and observations [14], [28], [29]. Data extraction involved identifying how the CECC operates (i.e., task elements), what information or SA is generated or transmitted (i.e., knowledge elements), and which ministries and agencies are involved for each operation (i.e., social elements). Data representation involved mapping task, knowledge, and social elements into networks. Task network illustrates the order for tasks/functions and their dependency. Knowledge network highlights the SA elements required to achieve these tasks. Social network illustrates the communication between governmental ministries and agencies to manage COVID-19 outbreak. These three networks were integrated to build the DSA combined network [27] for understanding *who, how,* and *what* was done in the control of COVID-19 in Taiwan.

III. Results

For the purpose of illustrating how CECC contributes to the resilience to COVID-19 in Taiwan, the results only include a simplified DSA network model to describe the task, knowledge, and social elements central to the CECC operations. The DSA combined network model (Fig. 1) shows a descriptive DSA model of CECC operations in containing COVID-19. Table I lists the abbreviations of the governmental ministries and agencies in the network model. Fig. 1 denotes task elements in black circles with white text, knowledge elements in white circles with black text, and social elements in texts besides each circle. Circles bordered with color are to ease the reader for linking the diagram with the description in the result section.

The DSA model shows that COVID-19 containment begun with disease identification and investigation functions performed by the TCDC to assess the epidemic situation that eventually led to the activation of the CECC (Fig 1). Based on an alert of an unknown disease in Wuhan through official updates from the World Health Organization (WHO) and social media [30], the TCDC sent a medical team to Wuhan to investigate the disease [31]. TCDC advised airports in Taiwan to start screening and reporting travelers, who might have been to Wuhan and showed symptoms of illness. With increasing cases of COVID-19 reported in China, TCDC officially activated the CECC to facilitate coordination across different ministries and agencies for containing COVID-19 [12].

Upon activation of the CECC, the National Security Council convened to identify representatives from relevant ministries

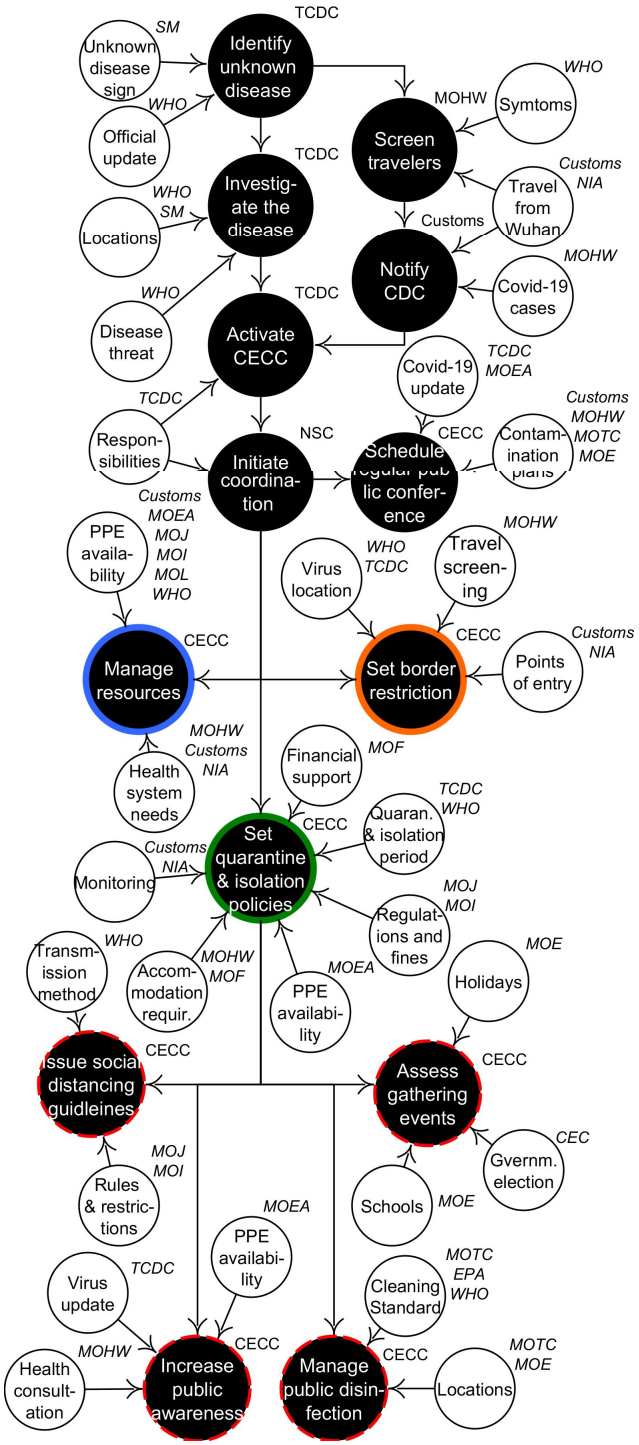

Fig. 1. Simplified DSA network model combining social, task, and knowledge elements characterizing the TCDC and CECC operations in managing the COVID-19 in Taiwan. Circles in black with white texts denote tasks whereas circles in white with black texts denote knowledge. Acronyms besides the circles denote ministries or agency roles (Table. I), with plain texts associated with tasks and italic texts associated with knowledge. The orange, blue, and green bordered circles indicate major functions/efforts by the CECC to manage COVID-19. The dotted circles indicate functions/efforts after setting quarantine and isolation policies.

and agencies to serve on the CECC [12]. The CECC members and structure were determined according to the TCDC assessment for each disease outbreak. For COVID-19, the CECC was first formed with representatives from the Ministries of Health and Welfare, Economics, Transportation, Education, Labor, and Environmental Protection Administration to manage the outbreak. The situation-specific structure and diverse members of the CECC enabled efficient acquisition and dissemination of information across many facets in the society necessary for managing COVID-19.

The CECC efforts in managing COVID-19 can be described in terms of: (1) controlling the borders, (2) managing medical resources, and (3) setting policies and regulations on managing infected individuals for containing COVID-19. The CECC also schedules regular public conferences to update the public on the COVID-19 situation and containment plans [32].

TABLE I. DESCRIPTION OF GOVERNMENT MINISTRIES AND AGENCIES INVOLVED IN MANAGING COVID-19 PANDEMIC

Abbreviation	Governmental Ministries and Agencies
CEC	Central Election Commission
CECC	Central Epidemic Command Center
EPA	Environmental Protection Administration
MOE	Ministry of Education
MOEA	Ministry of Economic Affairs
MOF	Ministry of Finance
MOHW	Ministry of Health and Welfare
MOI	Ministry of Interior
MOJ	Ministry of Justice
MOL	Ministry of Labor
MOTC	Ministry of Transportation and Communications
NCC	National Communications Commission
NIA	National Immigration Agency
NSC	National Security Council
SM	Social Media
TCDC	Taiwan Centers for Disease Control
WHO	World Health Organization

For border control (orange bordered circle in Fig. 1), the CECC chiefly coordinates with four ministries and agencies strategically to minimize the spread and support contract tracing of COVID-19 [29]. The CECC acquires SA on infected countries from the TCDC which uses WHO electronic reports and media briefings to identify countries from where visitors could create public health risks. This SA enables the CECC to formulate the border control policy of (1) which countries to ban travel and (2) thus which travelers to screen upon arrival. The CECC transmits this policy to the Ministry of Foreign Affairs for enacting travel bans on selected countries. Further, the Customs and National Immigration Agency are also informed of the policy and in turns provide information to the CECC on the ports necessary to (1) establish a screening process (e.g., electronic or paper health declaration) for maintaining traveler information, and (2) mobilize workers and equipment for screening. The CECC transmits the resource requirements for each port to the Ministry of Health Affairs for deploying their workers and equipment for screening travelers and obtaining their information in collaboration with Customs and Immigration personnel. The screening process by the Ministry of Health Affairs, Customs, and Immigration generates the SA or information about infected individuals for contact tracing and quarantine/isolation.

For medical resource management (blue bordered circle in Fig. 1), the CECC works with five ministries and agencies to ensure sufficient PPE and hospital capacity for responding to potential COVID-19 outbreaks [33]. To ensure PPE effectiveness and availability, the CECC first assesses mask protection requirements based on WHO and TCDC electronic reports. Then, the CECC works with the Ministry of Economic Affairs to compare the requirements against the Taiwan mask standards, estimate current stock level for the country, and assesses production capacity and needs. The coordinated situation assessment of PPE provides CECC with the SA to (1) determine necessary production level, and (2) formulate regulations on export, price, and purchase limits on masks. The CECC transmits the SA on necessary mask production to the Ministry of Labor for actions to increase capacity. Further, the CECC transmits regulation on masks to (1) the Customs for prohibiting trades/exports, and (2) the Ministry of Economic Affairs for monitoring local markets. The CECC also communicates the temporary regulations to the Ministry of Justice who in turn notarizes fines and penalties for illegal trading and coordinates with the Ministry of Interior on enforcement. After ensuring masks availability, the Ministry of Economic Affairs authorizes specific retailers for selling masks (e.g., pharmacy, supermarket) and communicates this information to the CECC which develops a software application for capturing and disseminating retailer information. The retailer information includes location, mask inventory, and contact information. The application allows authorized retailors to update their inventory level.

On ensuring the availability of medical services, the CECC obtains information on COVID-19 treatment capacity of hospitals and doctors from statistics and documents provided by the Ministry of Health and Welfare [34]. This SA on medical service capacity motivates the CECC on issuing a travel ban on medical practitioners that is communicated to the Ministry of Health and Welfare for informing medical professionals and Customs and Immigration.

For preventing infected individuals from spreading COVID-19 (green bordered circle in Fig.1), the CECC assessed and coordinated quarantine and isolation operations with seven ministries and agencies [35]. The CECC first gathers information on COVID-19 transmission, symptoms, and treatment from WHO and TCDC. By assessing the information to determine the infectious nature of COVID-19 and PPE availability, the CECC (1) establishes proper quarantine and social isolation policies and regulations, and (2) assesses the resources, such as money and facilities, to support citizens, travelers, and workers affected by COVID-19. The CECC quarantine and isolation policy and regulations (e.g., time to stay home, accommodation requirements, emergency numbers, fines) are sent to the Ministry of Health and Welfare and Immigration to inform (1) individuals tested COVID-19 positive and (2) travelers entering the country of these regulations and policies. Further, the CECC gives the regulations to the Ministry of Justice to notarize and the Ministry of Interior to enforce the policies and regulations. Lastly, the CECC requests financial supports from the Ministry of Finance for budgeting. The CECC then provides the budget on providing accommodation for quarantine and isolation to (1) Customs and Immigration to

assess travelers who need accommodations and (2) Ministry of Labor to provide financial assistance to workers affected by COVID-19. Further, the CECC uses the information on travelers' accommodation collected by Customs to support contact tracing.

After setting quarantine/isolation policies and regulations, the CECC performs four major coordination activities to contain COVID-19 (red dotted circles in Fig. 1): (1) assess upcoming public and social gathering events, (2) manage public places disinfection, (3) issue social distancing guidelines, and (4) increase public awareness.

The CECC coordinates with three agencies to assess the spread of COVID-19 related to major events and gatherings for schools or holidays [36]. The CECC assessment helps formulate the operational policy for school opening, public gathering, and political events. The CECC transmits the policy to (1) the Ministry of Education to postpone school opening, (2) the Ministry of Interior to prevent any public celebration or gathering, and (3) the Central Election Commission to postpone elections.

The CECC manages public disinfection by coordinating with four ministries and agencies to limit the spread of COVID-19 [12]. The CECC uses the knowledge on the infectious nature of COVID-19 (as described previously) to (1) establish cleaning standard and (2) determine location to disinfect. The CECC transmits the standards and locations to (1) the Ministry of Education to coordinate with Environmental Protection Administration for disinfecting schools, and (2) the Ministry of Transportation and Communications to disinfect public transportation and airports.

The CECC issues social distancing guidelines in coordination with two ministries and agencies to control social interactions during the pandemic [37]. With the knowledge of the infectious nature of COVID-19, the CECC establishes guidance and regulations for safe social interactions. The CECC coordinates with the Ministries of Justice and Interior to notarize and the National Communications Commission to broadcast in the media. This coordinated dissemination of the social distancing guidelines ensures public awareness of the social distancing situation and seriousness.

The CECC constantly works on increasing public awareness about COVID-19 by coordinating with two ministries and agencies [12]. The CECC holds public briefings to disseminate the most up-to-date SA on COVID-19 according to the TCDC assessment and establishes call centers to answer individual inquiries and provide personalized advice. Further, the CECC assesses the call center inquires to determine public messaging necessary for improving social habits or reducing misinformation. The CECC coordinates with the Ministry of Health and Welfare and the National Communication Commission to broadcast COVID-19 campaign messages on various media.

IV. Discussion

The purpose of this research is to illustrate that resilience to disease outbreaks in developed countries can be engineered through a provisionary command center which facilitate non-routine information processing (i.e., situation assessment) and transmission (i.e., SA transactions) across multiple government agencies as demanded by the crisis. To illustrate how facilitating non-routine situation assessment and SA transactions by a provisionary command center can provide resilience, the CECC operations for containing COVID-19 in Taiwan are modeled using the DSA framework. The DSA model depicts the COVID-19 driven CECC tasks concerning situation assessment along with the SA transactions that enable the government agencies and citizens to respond in a coordinated manner for containing COVID-19. The Taiwan response to COVID-19 is considered the prime example of success against pandemics [30], [38], [39].

This case study of modeling DSA for the CECC COVID-19 containment operations in Taiwan contributes to the DSA and resilience literature. First, our novel application of DSA framework results in a model that is useful to understand the task, knowledge/SA, and social elements in the CECC operations for managing COVID-19. The DSA combined network model illustrates the types of SA transactions between government agencies in order to provide an effective response. For example, to manage PPE resources, the CECC relies on SA transactions between more than six agencies. By capturing the SA transactions between CECC and other agencies, the DSA model also highlights the non-routine situation assessment and SA transaction activities essential only during the time of COVID-19 and possibly for other disease outbreaks. These non-routine activities are thus illustrative of the adaptive role that the CECC serves in supporting situation assessment, policy formulation, communication, and coordination across many government agencies during COVID-19. In other words, the DSA model indicates the temporary services and re-organization necessary during a crisis. For example, during pandemics, Customs and Immigration must be aware of high-risk countries and traveler information to collect for border management. Rather than relying on self-adaptation within Customs and Immigrations, whose expertise is on border control operations rather than pandemic controls, the CECC assess risk levels of individual countries and inform the Ministry of Foreign Affairs, as well as Customs and Immigration on necessary travel bans. In summary, the DSA model illustrates the unique expertise and services of the CECC that would be challenging for other government ministries or agencies to provide for the society in controlling the outbreak.

This case study also illustrates the research connection between DSA and resilience. As mentioned, the DSA network model captures the non-routine services in situation assessment, policy formulation, communication, and coordination provided by the CECC during the COVID-19 pandemic. In terms of fundamental concepts of resilience [40], the DSA network model illustrates an interorganizational system architecture that can provide graceful extensibility of various government functions and sustained adaptability of the government agencies against disease outbreaks.

In particular, the DSA model of the CECC suggests that a provisionary command center is a viable component in the system architecture to connect non-routine processing and communication of essential information across existing government agencies whose proficiencies are largely unrelated to pandemics. The connections supported by the provisionary command center enable the permanent agencies to extend their

services gracefully beyond their typical practice for containing an unknown disease.

In addition, the DSA model illustrates that interorganizational system architecture with a provisionary component may provide the sustained adaptivity responding to different crises over time. Assigned with only a predefined mission, the CECC is only a provisionary command center, of which the structure and members are established according to the demand of the situation. That is, the provisionary command center focuses on the role of adapting existing services of various government agencies which can then focus on the operational aspects of the adaptation. Such system architecture with explicit adaptive components may be helpful for sustained adaptivity as the permanent components typically need to focus on optimizing routine operations.

This study has several limitations. Our DSA modeling method only includes publicly available documentation and information without any supplements of interviews and observations of the CECC during the COVID-19 outbreak. Greater access to the CECC operations and staff could help with model verification. The effectiveness of COVID-19 response in Taiwan also cannot solely be attributed to the establishment of the CECC. Other geopolitical and social factors could also play a significant role in COVID-19 containment. For example, prior outbreaks have led to greater cautions for early government response and social acceptance of wearing masks.

V. Future Work

Future work will focus on examining the effective COVID-19 response of countries beyond Taiwan to identify other operations that yield resilience to disease outbreaks. Further, research should also examine the design for global resilience to disease outbreaks in a manner that can overcome geopolitical barriers. Modeling and simulation methods should be investigated to complement the qualitative DSA research effort in providing design recommendations in terms of task to perform, knowledge to acquire, and organizations/personnel to involve. Quantifying DSA description of command centers can yield a formal evaluation of design and resilience of infrastructure against disease outbreaks.

VI. Conclusion

The Taiwan response to COVID-19 demonstrates that a provisionary command center known as the CECC could play a role in providing the resilience of the society against disease outbreaks. The DSA framework is applied to model the CECC operations, illustrating that the provisionary command center facilitates the non-routine situation assessment and SA transaction activities across multiple ministries and agencies. The DSA network model captures an interorganizational system architecture for managing COVID-19 in Taiwan. Further, the DSA model indicates how the provisionary command center can support graceful extensibility and sustained adaptivity of the services provided by a wide range of government agencies. Thus, the DSA framework can be useful for investigating fundamental concepts of resilience and designing a provisionary command center for managing disease outbreaks.

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