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Enhancing Hospital Planning Capacity and Resilience in Crisis Scenarios Using Interpretive Structural Modeling (ISM)

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Master in Management

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FORMULAÇÃO DE RECOMENDAÇÕES DESTINADAS AO AUMENTO DA RESILIÊNCIA HOSPITAL EM CENÁRIOS DE CRISE: UMA ABORDAGEM SOCIOTÉCNICA COM RECURSO A *INTERPRETIVE STRUCTURAL MODELING* (ISM)

ABSTRACT

Os hospitais são infraestruturas críticas. No confronto com desastres naturais, doenças infeciosas ou outras crises que afetem gravemente a oferta e a procura de serviços médicos locais—e que até põem em risco o próprio hospital—, o hospital precisa, em primeiro lugar, de assegurar as funções essenciais de emergência e, em segundo lugar, de recuperar desses impactos o mais rapidamente possível. A resiliência do hospital tem numerosos elementos de influência e critérios de avaliação, mas existem ainda fronteiras ambíguas nas suas relações de influência interna e nas suas estruturas hierárquicas. Neste contexto, o presente estudo explora determinantes e práticas para reforçar a resiliência hospitalar a partir de uma perspetiva de gestão interna, aplicando métodos de tomada de decisão de grupo e *Interpretive Structural Modeling* (ISM) para reunir o conhecimento e a experiência de especialistas em áreas relacionadas e identificar variáveis críticas. Com base na informação recolhida, foi estabelecido um modelo hierárquico de resiliência hospitalar. Os resultados e a aplicabilidade prática do modelo foram validados por peritos externos, no sentido de fornecer novos conhecimentos para o desenvolvimento da gestão da resiliência hospitalar.

Palavras-Chave: Capacidade de Planeamento Hospitalar; Gestão Hospitalar; *Interpretive Structural Modeling* (ISM); Resiliência Hospitalar.

Códigos JEL: I10; H12; D81.

ENHANCING HOSPITAL PLANNING CAPACITY AND RESILIENCE IN CRISIS SCENARIOS USING INTERPRETIVE STRUCTURAL MODELING (ISM)

ABSTRACT

Hospitals are the critical support infrastructures. In the confrontation with natural disasters, infectious diseases, and other crises that severely affect the supply and demand of local medical services—and even jeopardize the hospital itself—, the hospital needs first to secure the essential emergency functions and, secondly, to recover from the impact as quickly as possible. Hospital resilience has numerous influencing elements and evaluation criteria, but there are still ambiguous boundaries in their internal influence relationships and hierarchical structures. Therefore, this study explores the determinants and pathways of practice for strengthening hospital resilience from an internal management perspective, applying Group Decision Making and Interpretive Structural Modeling (ISM) to pool the knowledge and experience of experts in related fields and identify critical variables. Based on the information collected and analyzed, a hierarchical model of hospital resilience was established. The results and practical applicability of the model were then validated by external experts to provide new knowledge for the development of hospital resilience management.

Keywords: Hospital Management; Hospital Planning Capacity; Hospital Resilience; Interpretive Structural Modeling (ISM).

JEL Codes: I10; H12; D81.

EXECUTIVE SUMMARY

Hospitals perform an extremely fundamental role in providing essential healthcare services to citizens. As a vital regional facility, hospitals should, firstly, maintain their operation as supporting infrastructure in crises and provide necessary medical and health services to residents. Secondly, they should restore their original treatment capacity or even surpass their original risk response capacity as soon as possible after crisis mitigation. This requires hospitals to strengthen their resilience management and planning capacity. Especially in 2020, Covid-19 has made academics and practitioners emphasize the construction of hospitals' crisis management and risk assessment capabilities. However, to reinforce these capabilities, hospitals must identify the complex relationships among their components. To explore the relevant determinants and relationships, this dissertation proposes using Interpretive Structural Modeling (ISM) to analyze this topic and understand optimization paths in hospital management practice. Retrospectively, this study argues that the concept of hospital resilience, although relatively young, has been reasonably well developed over the past decades due to its prominence and operational orientation. Researchers in various countries have proposed many frameworks and evaluation metrics for building resilient hospitals or healthcare systems based on major public health events (*e.g.*, Ebola and SARS) and natural disasters (*e.g.*, earthquakes). This study also found that exploring factors and hierarchical and structured relationships within the perspective of internal hospital management still needs improvement, which becomes our probe's landing point. Thus, the researcher designed the expert panel, including hospital administrators, clinical operations managers, engineers, and government officials from health-related departments. Based on their professional knowledge and practical experience, this study first identified ten determinants, including *hospital organizational capacity*, *leadership*, *ability to react to abnormal events*, etc., through Group Decision Making. Then, the researcher compiled the expert consensus into a Structural Self-Interaction Matrix (SSIM) under the ISM framework and transformed it into an Initial Reachability Matrix (IRM) using a binary approach. Finally, the Final Reachability Matrix (FRM) was obtained by Level Partitioning, and a five-layer ISM model was built based on it. In addition, the results of FRM were used for a *Matrice d'Impacts Croises Multiplication*

Appliqué a un Classement (MICMAC) analysis. The MICMAC system was used to identify the critical factors that influenced the implementation of the ISM framework. Among the ten determinants in this study, four are in the *dependent* quadrant, four are in the *independent* quadrant, and two more are within the *autonomous* quadrant. Experts from the School of Health Management, Southern Medical University, China, concluded a discussion with the researcher, providing evaluation and suggestions on model applicability and practice logic, analyzing the limitations of this study, and pointing out potential research directions.

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MAIN ABBREVIATIONS USED

FRM – Final Rechability Matrix
GDM – Group Decision Making
IRM – Initial Reachability Matrix
ISM – Interpretive Structural Modeling
MICMAC – *Matrice d'Impacts Croises Multiplication Appliqué a un Classement*
NGT – Nominal Group Technique
SSIM – Structural Self-Interaction Matrix

CHAPTER 1

INTRODUCTION

1.1. Initial Background

Hospitals are complex organizations that provide a wide range of open-end healthcare services to the public. Due to its complexity, hospitals are often assigned different attributes and qualities. Shared external perspectives include production function, technological and bio-pharmacological capacities, information systems, and institutional and network-based concepts of providers of complex services and healthcare system hubs (Djellal & Gallouj, 2007). From within the organization, an hospital is a combination of both physical and administrative firms (Harris, 1977). In recent years, the frequency and related disruptions of disasters have increased (Michel-Kerjan, 2011), including natural disasters, pandemics, and terrorism. The impact is often more pronounced in areas that lack preparedness but have large populations and fragile healthcare infrastructures (Achour, Miyajima, Pascale, & Price, 2014). The importance of healthcare systems in developing and strengthening disaster resilience thus has become highly self-evident (Cristian, 2018). The notion of hospital resilience is then put forth by researchers to understand the status (Zhong, Hou, Clark, Zang, Wang, Xu, & FitzGerald, 2014).

In the extant research on hospital resilience, the focus on comprehensive management elements still needs to be improved. From the hospital management perspective, internal and external factors are intertwined (Rosko, 1999), highlighting the significance and challenge of identifying optimal pathways. These factors, in turn, intersect with the evaluation indicators of different dimensions, further making it difficult to analyze and rationalize the corresponding logical models in the practice of enhancing hospital resilience and planning capacity. This study thus begins to explore the most relevant factors and their influential relationships, and aims to develop a structural model and critical path for enhancing hospital resilience. The results of the present study will overcome some limitations in previous studies and provide some references for hospitals to strengthen their emergency response capacity and improve their operational management readiness.

1.2. Research Objectives

As outlined above, exploring the elements and influencing relationships that optimize hospital resilience and planning capacity is somewhat complex. Experts with experience and expertise in this area will have their subjective thinking. In this context, conducting research requires bringing together the knowledge and capabilities of decision-makers to include a broad and deep range of different voices. Therefore, in this dissertation, two approaches are used to explore the study topic: (1) the application of the group decision-making process for identifying key determinants and their interrelationships; and (2) the conduct of the Interpretive Structure Modeling (ISM) technique for analyzing and deriving hierarchical structures among different elements. The final model obtained from the study would help decision-makers better understand the path and mechanism behind strengthening hospital resilience.

This study was conducted in an online session with several expert panel members around hospital management, especially in emergency management, to explore the topics in depth. The session consisted of two parts, in which the experts first discussed the essential determinants, and then identified their influence relationships in pairs based on the ISM framework. After the agenda, the researcher performed the ISM extrapolation calculations. The obtained model result was provided to another practitioner to discuss the model’s feasibility and applicability further.

1.3. Methodological Guidelines

The principal research methods in this dissertation are Group decision-making and ISM technique to explore the elements and patterns of influence that strengthen resilience and planning capacity from the hospital management perspective. Following a comprehensive review of the literature, the methods were developed sequentially in the following two phases of this study. The first approach facilitates the identification of decision criteria for ISM and construction of a relationship matrix (Cheng, Chiu, Tseng, & Lin, 2007). The study first collects expert opinions and forges consensus by contributing expertise and empirical knowledge through a nominal group technique. Secondly, applying ISM transforms the factors and relationships extracted in the previous session into binary matrices. ISM and MICMAC analyses are then carried out to finalize the hierarchical structure model.

Given the control specification of China Covid-19 and the geographical distance between panelists and researchers, the nominal group of this study was held online. Simultaneously, while retaining the quality of in-person session interviews, the online group facilitated participants to discuss candidly and share in-depth stories, especially on sensitive topics (Woodyatt, Finneran, & Stephenson, 2016), thus enabling thorough exploratory research on hospital resilience.

1.4. Structure

This dissertation has five chapters, commencing with Introduction and ending with a Conclusion. A list of references applied in this paper follows the main text, and part of the computational procedure in *Chapter 4* is at last as an appendix.

Chapter 1 outlines an overview of the paper, starting with the essential background, purpose, methodology, article structure, and expected study results of enhancing hospital resilience and panning capacity under crisis scenarios. *Chapter 2* provides a critical review of the research-related literature, including a rationalization of crucial concepts such as hospital resilience and a retrospective survey of the contributions and limitations of previous theoretical models. *Chapter 3* then provides an in-depth discussion of the theoretical underpinnings and current development of the methodological tools used in this study. These methodologies include: (1) group decision-making for pooling and retrieving expert knowledge and experience; and (2) ISM technique and MICMAC analysis for exploring the hierarchical structural connections among influencing factors. The value of these methods for this study is also discussed in this section. *Chapter 4*, Results and Discussion, provides a detailed account of the experimental process and the derivation of the study results. In the second stage of the interview, the experts reached a consensus on the relationships based on the ISM framework and generated a matrix for the subsequent analysis. Upon expert panel session, this study calculated the hierarchical structure among determinants using ISM and categorized the system elements using the MICMAC method for proposing the corresponding optimization strategies. The researcher then invited an external party to validate and comment on the model results and to make suggestions for this study. *Chapter 5* concludes by presenting managerial implications for enhancing hospital resilience, exploring the findings' limitations, and specifying potential directories.

1.5. Expected Results

This paper examines hospital resilience and planning capacity from an integrative management perspective and proposes a hierarchical structure model of ten critical determinants. This model facilitates the decision-makers’ understanding of the transparency and constructive nature of elemental relationships in response to a crisis and allows for a proactive and feasible optimization trajectory for hospital management practices. It is thus a beneficial complement to previous studies. The results of this study are also intended for subsequent publication in an international journal.

CHAPTER 2

LITERATURE REVIEW

This chapter intends to clarify the concepts of hospital planning and hospital resilience. Hospital resilience is quite general in nature. The various models and evaluation criteria developed with its objectives also become the focus and analysis of this section. We will discuss the current studying status in the related field, identifying the domains and dimensions adopted by different models. The gaps and limitations of current research will then be explored. The dissertation will thus position an overall objective and appropriate methodology to contribute to the research topic. The result of this review will delve into strengthening hospital resilience.

2.1. Basics of Hospital Resilience

The word *resilience* is derived from the Latin word *resilio*. The Merriam-Webster Dictionary defines resilience as: (1) the capability of a strained body to recover its size and shape after deformation caused especially by compressive stress; and (2) an ability to recover from or adjust easily to misfortune or change. Under scientific context, the concept of resilience is now used in a great variety of interdisciplinary work concerned with the interactions between people and nature (Klein, Nicholls, & Thomalla, 2003), including psychology, psychiatry, sociology, as well as biological fields like genetics, epigenetics, endocrinology and neuroscience (Herrman, Stewart, Diaz-Granados, Berger, Jackson, & Yuen, 2011).

Wald, Taylor, Asmundson, Jang, and Stapleton (2006) say that the study of resilience started with learning maltreated children. Researchers used the term to describe three kinds of phenomena, namely: (1) good developmental outcomes despite high risk status; (2) sustained competence under stress; and (3) recovery from trauma. Each of these conditions focus on protective factors or mechanisms to moderate reactions to stressful situations or chronic adversity (Werner, 1995). In people's lives, resilience may lie in both preceding and succeeding circumstances connected with turning points. The turning points turn people from maladaptive life path into an adaptive trajectory (Rutter, 1993).

The study of individual scenarios is the commencement of the resilience topic. It, in fact, serves diverse systems despite personal factors. It is a concept that refers to the capability of a system (*e.g.*, group, community, family, or ecosystem) to bounce back from adversities and disasters. Researchers regard resilience as an interactive capacity. The more traditional theory focuses on equilibrium steady-state, emphasizing resistance to disturbance and speed to return to the equilibrium (Pimm, 1984), while other definitions look at the extent the system could mitigate or absorb disturbance that may change its structure and behavior (Holling, Schindler, Walker, & Roughgarden, 1995). The United Nations International Strategy for Disaster Reduction (UNIDRR, 2004, p. 16-17) defines the term resilience as *"the capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure"*. After decades of debates, it is considered that the definition of resilience has *"become an umbrella concept for a range of system attributes rather than a practical policy or management tool"*.

Natural disasters, technological catastrophes, terrorism, unknown viruses, and other destabilizing factors have led researchers to focus on the role of resilience in organizational recovery and real world. The interdisciplinary cross-development has made the concept of a resilient hospital more complex, and the understanding of resilience has become more profound and diversified. However, the lack of a cross-dialogue mechanism between various fields has led to the difficulty of multidisciplinary theories of resilience research in a problematic scenario (*i.e.*, hospital with good research validity).

The concept of hospital resilience was introduced at the World Conference on Disaster Reduction to ensure that all new hospitals have a level of resilience that can enhance their ability to remain functional in a crisis (Albanese, Birnbaum, Cannon, Cappiello, Chapman, Paturas, & Smith, 2008). There is an international consensus on the importance of building resilient hospitals, but researchers have yet to reach a standardized concept. Cristian (2018) states that hospital resilience is the ability of a hospital to withstand, absorb, and respond to a disaster while maintaining critical functions and then return to its initial state or adapt to a new state.

Aburn, Gott, and Hoare (2016) consider hospital resilience as the level of support and structure around individuals or communities and their ability to access support in times of crisis. Zhong, Clark, Hou, Zang, and Fitzgerald (2014a) define it as the ability of hospitals to resist, absorb and cope with shocks while maintaining surging healthcare needs. The current consensus is that hospital resilience refers at least to the ability of hospitals to demonstrate a return to the norm or even beyond the norm in extraordinary situations, which must include unexpected short-period emergencies, such as significant epidemics and earthquakes.

Researchers hold different views on including chronic external constraints in long-term states in unexpected emergencies. For instance, Sternberg (2003) points out that disasters are a subset of crises and that hospital resilience has different meanings in response to major disasters and other difficulties. There are also scholars pointing out that organizational resilience in public hospitals is not only the ability to recover from short-term emergencies but should also include the ability to absorb, adapt, change, and innovate (*e.g.*, Xue *et al.*, 2020). Similarly, Cimellaro and Piqué (2016) argue that the concept of resilience applies to both the short and long term. Shirali, Azadian, and Saki (2016) divide it into time phases and point out that organizational resilience includes not only response sessions but also the prediction of crises, monitoring of threats, and post-event reflection and learning should be included in the scope of resilience. Overall, resilience is a systematic concept.

The most fundamental core competency of hospital resilience is the ability to provide emergency medical services and ensure part of regular health services in times of crisis, followed by the ability to recover or even break through to the original state after crisis mitigation. Under a more integrated view, a higher level of resilience consists of prediction, response, recovery, and growth of unstable states. The following section will explore the role and value of developing hospital resilience.

2.2. Reasons for Hospital Planning and Resilience

Turner and Pidgeon (1997) claim that there is no universally accepted definition of disaster, yet it is self-evident that it involves threats of injury and loss of life. They classified natural and man-made disasters, and management procedures must be maintained throughout the process. A crisis is *"an abnormal situation which presents some extraordinary, high risk to business and which will develop into a business unless carefully managed"* (Shaluf, Ahmadun, & Said 2003, p. 29), and crisis requires immediate decisions in critical situations. The meaning of crisis in Chinese (*i.e.*, *wei-ji*) is a combination of "danger" and "opportunity". We can thus also embrace an expectation that risk breeds new life of business. Following the 2014 Ebola outbreak in West Africa, health system vulnerability has attracted widespread attention around the world. Subsequently, building the resilience of health systems to withstand shocks caused by different factors (*e.g.*, natural disasters, infectious diseases, or mass injuries) has become one of the leading topics in global health policy research and disaster reduction (World Health Organization (WHO), 2016). Health systems that protect human lives and deliver good health outcomes for all during and after a crisis are resilient (Masten, 2001). Hospitals as basic units of the health system, and the resilience of the system needs to be ultimately reflected in hospital resilience in order to better respond to and deal with emergencies like public health events.

Hospitals are complex social systems in which organizational coordination, effective integration of member attitudes and motivations, and good interpersonal relationships are significant. Nevertheless, the modernization of hospitals constantly generates new difficulties and challenges (Georgopoulos & Matejko, 1967). After the occurrence of an event, the interaction between various entities and elements of the system and the external environment creates a new complexity. The hospital operation network consist of a large number of demand points, hierarchical supply nodes and equipment terminals, and each entity exhibits different degrees of traffic variability and spatial dispersion. First, a hospital consists of numerous organizational nodes, including interconnection of facilities and equipment, demand and supply of resources, and space allocation and other collaborative efforts to ensure the normal operation of the hospital. These nodes differ from each other, each does its own job in the network, cooperate with each other in the time and space dimensions, and depend on each other as the inherent basis of network synergy. The dynamic relationship between the nodes of the hospital organization forms the infrastructure for coping with and managing risks and crises caused by external and internal changes in the situation. Second, the informal social network formed by healthcare activities has different stakeholders (*e.g.*, physicians, patients, and upstream suppliers) regarding resource, information, and financial flows, forming collaborative behaviors as well as supply and demand relationships that drive the system to always maintain a dynamic state of regulation and frequent environmental interactions (Jha & Epstein, 2010). Finally, the shape of the hospital operation network is dynamically changed by the external environment, and one typical manifestation of this change is the sudden change in the supply or demand of medical services in the market, such as COVID-19 on public health in the form of a pandemic, during which a surge of patients leads to an exponential increase in the demand for inpatient beds, intensive care units, ventilators, protective clothing, and other resources (Xue *et al.*, 2020).

As demonstrated by Beck (2009), who proposed the famous *Risk Society* theory, the immeasurable risks and man-made uncertainties associated with the triumph of modernity mark the human condition at the beginning of the 21st century. Therefore, being and positioning in this world increasingly involves an understanding of the confrontation of catastrophic risk. In the environment of volatility, uncertainty, complexity, ambiguity (VUCA), emergencies with high risk and significant consequence (*e.g.*, COVID-19) are likely to become more frequent and to grow in size and impact (Worley & Jules, 2020), and when they do occur they follow Murphy's Law to cause destructive damage (Bell, 1989). Uncertainty about demand (Boutsioli, 2010), supply capacity (Franco & Alfonso-Lizarazo, 2020), and public health emergencies (Mays, Smith, Ingram, Racster, Lamberth, & Lovely, 2009) can lead to substantial challenges for healthcare entities (*e.g.*, hospitals) and even the entire system. New emerging, unknown, or unconsidered risks may pose the greatest challenges to the resilience of operational systems. For instance, in facing the contemporary frequency of the flow of resources and information in the hospital network is complex and cannot be anticipated in advance of major infectious disease events, occupational hazards, and environmental contamination events, etc. The flow in the hospital network is so complex that it is barely possible to achieve early warning, timely control and effective response, which can easily turn into a large-scale public health crisis with enormous impact. These external factors further affect the internal elements of the hospital operation system and greatly increase the complexity of planning and scheduling. Establishing a resilient hospital has become crucial to its management and progression. The following section will review the current research findings.

2.3. Analysis of Extant Literature and Respective Limitations

Currently, hospital resilience has become a growing concept in the international health and development context (Stennett, Hou, Traverson, Ridde, Zinszer, & Chabrol, 2022). However, a comprehensive framework for measuring hospital core competencies currently still needs more consensus (Zhong *et al.*, 2014a). The role of a hospital resilience evaluation system is to provide programmatic guidance to ensure that each hospital can plan appropriately for handling emergency situations under crisis conditions.

There are few well-established systems in current research. A traditional approach of hospitals to challenges has focused on emergency preparedness based on a “4S” framework: staff, stuff, space, and systems (Harris, Rak, Kahn, Angus, Mancing, Driessen, & Wallace, 2021). The “4S” framework refers to the health care professionals needed to provide care, the medications and other supplies needed for treatment, the physical rooms and environments where patients receive care, and the systems needed to integrate these resources. Another representative system was proposed by Zhong, Clark, Hou, Zang, and Fitzgerald (2014b). This framework consists of 4 domains and 12 subdomains, which was validated in 41 tertiary hospitals in Shandong Province, China. Cristian (2018) considers this framework as a starting point for a broad consensus on the core elements of hospital resilience and consented that the system development approach was the basis of the framework study. *Figure 2.1* supports this perspective.

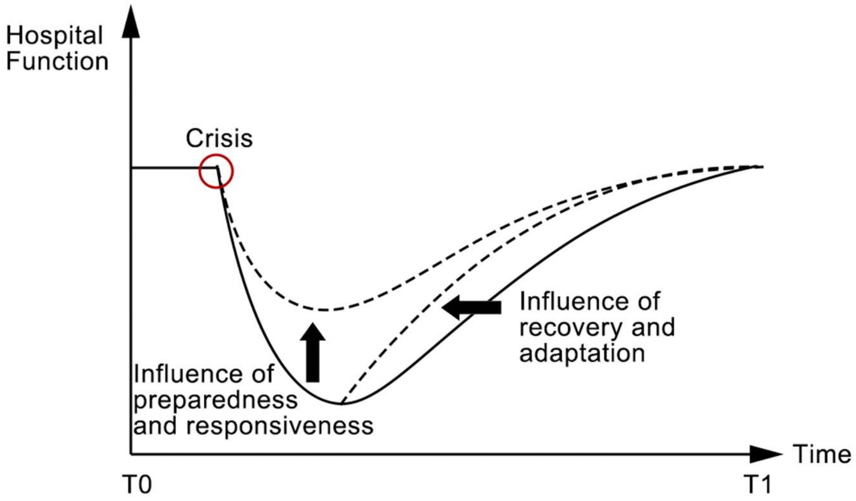


Figure 2.1. Hospital Recovering Process.

(Source: Zhong *et al.*, 2014b, adap.)

Kruk *et al.* (2017) learned the lesson from Ebola outbreak in 2014, and adopted the concept of resilience to add dynamism and urgency to the health system. The authors built the conceptual framework of health system resilience index, which was composed of 5 capacities of being integrated, adaptive, aware, diverse, and self-regulating. To build in this way, the system is required to plan and invest in not only fast variables (*e.g.*, protective products, surveillance), but slow variable (*e.g.*, health professionals, information system) as well. A resilient health system is capable to reduce life loss, mitigate adverse health consequence, and minimize socio-economic disruption (Kruk, Myers, Varpilah & Dahn, 2015).

Fallah-Aliabadi, Ostadtaghizadeh, Ardalan, Fatemi, Khazai, and Mirjalili (2020) reviewed 32 articles and guidelines out of 1794 related studies to reach the indicators of hospital disaster resilience (HDR). The authors collected and categorized them into 3 domains (*i.e.*, constructive, infrastructural and administrative resilience) and 27 subdomains. Constructive resilience is a domain of hospital building. The infrastructural resilience means non-structural elements that also facilitate the hospital functions, and the administrative resilience was the domain of disaster management activities.

Zhang, Chen, Liu, Li and Sun (2019) emphasize that the capacity to absorb, adapt, reform and innovate stands at the core of organizational resilience, and that the core of the collective action framework of public hospitals includes public hospital assets, sociality, and collective action. Public hospitals should embed the concept of resilience into the daily practice operation of hospital control systems and explore the localization of organizational resilience for the specificity of each hospital.

Achour *et al.* (2014) surveyed 66 hospitals went through earthquakes in Japan. They paid much attention to the dependence of hospitals on external systems, and divided the resilient hospital system into physical and social factors. The health system faces three major challenges, namely the: (1) vulnerability of health care facilities to natural disasters; (2) low performance of alternative resources; and (3) failure to guarantee the supply of healthcare resources in disaster-resilient legislation.

Nuzzo *et al.* (2019) searched 1108 articles and identified 77 key documents that described 16 high-level indicators of health system resilience, including infrastructure, transportation, leadership plans, in addition to barriers to health care access, crisis financing, and changed standards of care. They further emphasized the need for increased integration of efforts to promote health security and health systems strengthening across the globe.

Barbash and Kahn (2021) suggest that in the context of COVID-19, resilient hospitals should have the following characteristics: (1) the ability to ensure high-quality care for the surge of COVID-19 patients (*e.g.*, specific wards that are fully staffed and equipped with physicians and associated health care staff to provide appropriate, guideline-compliant care. If such wards are not available, resilient hospitals can quickly and safely transfer these patients to hospitals that have the capacity to do so); (2) the ability to treat the surge of COVID-19 patients, especially those requiring cancer treatment, emergency cardiac care, and trauma surgery, with non-COVID-19 patient care standards; (3) the ability to ensure access to care for the general population of patients within the scope served, continue elective surgery and mitigate the exacerbation of health disparities during a pandemic; and (4) protect the well-being of front line healthcare workers while accomplishing all of the above, not only by ensuring adequate personal protective equipment, but also by making staff feel valued and connected to the organization’s mission.

A retrospective survey of the above concepts and literature will help this study to carry out more valuable and well-directed research, as explained in the following paragraphs.

2.4. Value Proposal

As explained, this chapter reviews key concepts and theoretical models from historical research. Hospital resilience is the capacity to retain emergency response from a crisis and to recover and even surpass the level reached before after the crisis has been mitigated. It is of critical value and contribution to the long-term sustainability of hospital organizations. The models addressed in this literature review cover essential elements for developing hospital resilience in contexts such as natural disasters (Achour *et al.*, 2014) and public health emergencies (Barbash & Kahn, 2021; Kruk *et al.*, 2017), thereby facilitating a theoretical and methodological reference for the conduct of this study. One may assume that existing literature delivers many indicative elements and evaluation instruments. However, the influencing relationships and hierarchical structures among the elements, especially from the perspective of internal hospital management, still need to be sufficiently explicit. This study was conducted with this as an entry point. The methodology adopted for the study will be described in detail in the next chapter.

SYNOPSIS OF CHAPTER 2

Chapter 2 presents a critical theoretical explanation and literature review of hospital resilience. It seeks to explain why healthcare systems need hospital resilience and how to position its concept. It also provides an overview of the frameworks proposed by different scholars in recent decades to build hospital resilience and their contributions and limitations. Finally, some constraints of previous studies are exposed to inform and justify new research for improvement. Hospitals are highly fundamental infrastructures in a regional ecosystem and play an irreplaceable and pivotal role in meeting the demand for healthcare services. Hospitals in crises face more significant uncertainty and risk of secondary crises due to the complexity of their operations, and the transfer of external risks carried to internal risks (*e.g.*, infectious diseases, natural disaster casualties). In addition to the regular hospital operational aspects of vulnerability, the more prepared (*e.g.*, infection plan, disease surveillance, backup power, and drugs), the more resilient in a crisis, which is demonstrated in the curve relationship of crisis onset-crisis response-post-crisis recovery. Also, hospitals possessing proactive and effective response capabilities (*e.g.*, emergency management, evacuation of personnel, immediate access to referrals) embrace greater capacity to reduce crisis-induced losses and casualties. Hospital resilience similarly requires that healthcare organizations have sufficient capacity to recover and adapt to new situations after a crisis. In particular, in public health crises (*e.g.*, Ebola, SARS, Covid-19), hospitals are called upon to collaborate with a broader range of practitioners to bring their healthcare expertise to bear on patient care and outbreak control in local communities. This chapter analyzes the historical literature's research perspectives and argues that many indicators and evaluation frameworks have been developed as significant advances in hospital resilience-related research in the past period. Nonetheless, this study likewise found that there still needs to be more clarity in identifying the elements' inter-factor influences and structural relationships. This deficiency has some research potential, especially from the perspective of internal hospital management, and also has promising practical benefits. This study, therefore, proceeds from this gap. The methodology used in this study will be interpreted in *Chapter 3*.

CHAPTER 3

METHODOLOGY

Chapter 3 discusses the research methodology used in this dissertation. In order to develop a framework that can effectively strengthen hospital resilience, a two-step approach was used in this study. First, a small group decision-making process was used to structure the framework derived from the literature review in *Chapter 2*. Second, online group sessions will be conducted to analyze the framework and data through Interpretive Structural Modeling (ISM) to construct a complete hospital resilience model.

3.1. Group Decision Making

A multi-attribute group decision problem is faced when multiple decision makers must choose the best solution from different alternatives based on a predefined set of attributes (Tzeng & Huang, 2011). This means that a Group Decision Making (GDM) problem is defined as a decision situation in which there are two or more experts, each of them characterized by his own perceptions, attitudes, motivations, who recognize the existence of a common problem, and attempt to reach a collective decision (Delgado, Herrera, Viedma, & Martínez, 1998).

GDM is conducive to pooling the wisdom of experts in different fields to deal with increasingly complex decision-making issues. Through the broad participation of these experts, they can make constructive opinions on decision-making issues, which is conducive to identifying problems and improving the targeting of decision-making before the plan is implemented. Researchers have come to numerous conclusions in determining the size of group decision-making. In the range of 6-12 people, member involvement decreases as group size rises, and 6 member size is conducive to emergent internal leadership (Bass & Norton, 1951). It was also suggested that within the 5-12 person range, the larger the number, the more resistant the group members are to reaching a consensus (Hare, 1959). In addition, between 2-6 people, the higher the number of people, the better and more consistent the decision quality achieved (Ziller, 1957). Borgatta and Bales (1955) found that groups of 6 people have higher solidarity and tension release. On the other hand, Cummings, Huber and Arendt (1974) concluded in their study that group solution quality is positively correlated with group size.

Group decision-making methods typically include: (1) *Brainstorming*: to generate ideas through brainstorming and publish them for others' reference and inspire everyone. Everyone has complete freedom to express their views without fear of personal embarrassment or criticism from others (Brahm & Kleiner, 1996); (2) *Delphi*: conceived in the early 1950s by RAND Corporation (Dalkey, 1969), the method enables experts' participation in solving problems as an anonymous mass. It uses multiple iterations to develop a consensus of expert opinion on a particular issue (Hsu & Sandford, 2007); (3) *Nominal Group Technique* (NGT): refers to the restriction of discussion and interpersonal communication among group members in group decision-making. When group members hold a meeting to make decisions, they must first make individual decisions, express their opinions separately, and then have a group discussion. The group is constrained by the task to produce structured and explicit output (Cantrill, Sibbald, & Buetow, 1996); and (4) *Stepladder*: group decision-making is formed by the continuous superposition of opinions of members from each group. This is a method to prevent group members from being unwilling to express their views directly under group pressure (Rogelberg, Barnes-Farrell, & Lowe, 1992).

Technology has a significant impact on how people discuss. Since the 1960s, technologists and policy makers have discussed remote distributed GDM via computer network. Face-to-face decision making probably is best when a decision requires complex thinking and subtle multiparty negotiations, and when problems are ill-defined. Yet, distributed decision making is said to make decision making more efficient and fair, and to purify interaction, removing irrelevant sources of bias such as personal charisma (Kiesler & Sproull, 1992). Among research approaches, Interpretive Structural Modeling (ISM) is built to decompose a complex system into smaller sub-systems and then develop a complex structural model of the overall system (Warfield, 1973). Therefore, ISM has the advantage of being more structured and systematic when exploring a compound factor model for empowering hospital resilience (Duperrin & Godet, 1973). In the next section, we will explore the details of ISM.

3.2. Interpretive Structural Modeling (ISM)

The ISM approach systematically applies some basic notions of graph theory, thus using conceptual, theoretical, and computational leverage to explain complex patterns of background relationships among a set of variables (Malone, 1975). It is a methodology for analyzing the structure of a system, which can decompose the complex and messy relationships between system units into a clear, multi-order structural form, and can also clearly describe the relationships between system elements (Attri, Dev, & Sharma., 2013). ISM has great advantages in describing the nature of the system, presenting the analysis results in the form of skeleton diagrams, which is intuitive and concise, and is widely used in modern system engineering because of its clear understanding of the causal hierarchy and ladder structure of the studied system factors.

Warfield (1973) proposed ISM, which is characterized by the use of people's knowledge and experience to decompose a complex socioeconomic system into several smaller subsystems with the help of computers, thus forming a structural model of the complex system. The model is characterized by multi-level recurrence. Attri *et al* (2013) reviewed studies of ISM and summarized six steps of conducting the approach. Through integrating and comparing various views and methodologies, the authors believe that ISM provides more systematic and efficient process to deal with complexities. ISM, with a lower threshold to participants, also offers practical guideline and record to formulate a structural model and graphic framework. It further serves as a learning tool to deepening the understanding of researchers on elements and relations within a system. The method emphasizes the influence of scenarios and contexts on the approach, which, from a general systems theory point of view, means that the specific environment in which the system is located will correspond to a change in the structure.

ISM is a conceptual model that is widely used in transportation, education, healthcare, natural disaster risk control, technology and performance assessment, risk management and control, standards development, product and service systems, supplier development and management, supply chain management, mobile payments, etc. (*e.g.*, Kumar, & Goel, 2022; Raj, Shankar, & Suhaib, 2008; Thakkar, Deshmukh, Gupta, & Shankar, 2006), because it can represent ambiguous ideas in intuitive structural relationships, thus enabling a more objective analysis of problems. Solving reachability matrix and inter level partitioning of element sets are two core parts of the ISM calculation, but frequent intersection operations make the calculation tedious when dealing with a large number of system elements. It is the decomposition of a complex system into several subsystem elements, and then through people's practical experience and knowledge with the help of computers, a multi-level recursive structural model is finally formed.

The role of ISM is manifested in three aspects (Huerga, Silvera, & Turoff, 2015): (1) identifying the influence of system elements (*i.e.*, the influence of an element on the system is not only related to the elements directly connected to the element, but also to the elements indirectly connected to the element). ISM can show the direct or indirect influence of the element in a concise and intuitive way, thus reflecting the role played by the element in the system as a whole; (2) analyzing the overall structure of the system (*i.e.*, the final result of ISM can be represented by a skeleton diagram containing each element). The diagram can not only show the direct and indirect logical relationships of the elements within the system, but also the overall structure of the system by way of topological hierarchy, which is easy to understand the system intuitively; and (3) analyzing the potential causes of system problems (*i.e.*, system problems are related to the overall structure of the system and the logical relationships between elements, and the skeleton diagram can precisely represent the overall structure of the system and the logical relationships between elements). Therefore, system problems can be clearly expressed through each logical structure, and it is easy to discover the internal logic of the problems. *Figure 3.1* is a flow chart of ISM procedures.

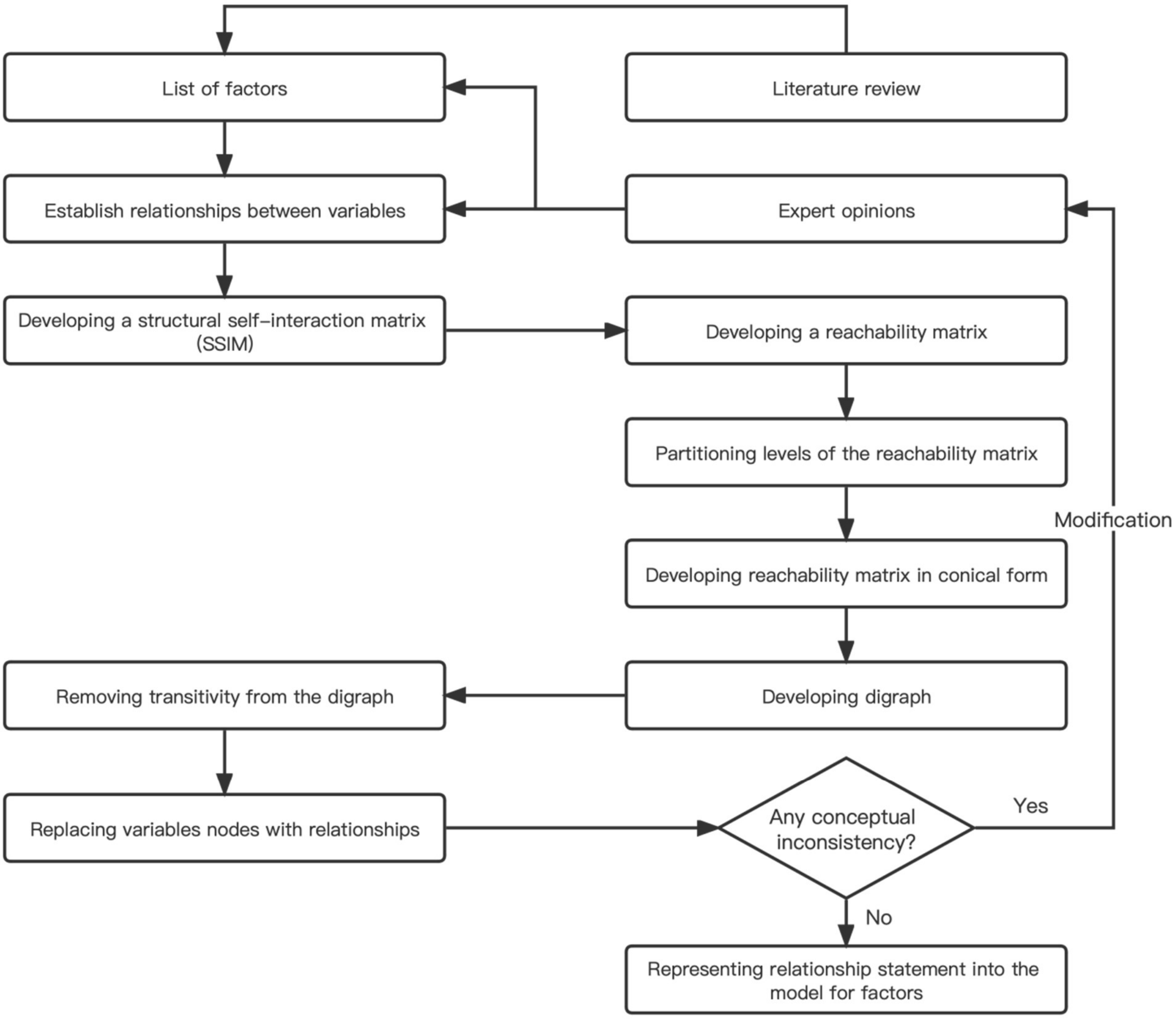


Figure 3.1. Flow chart of ISM procedures.

(Source: Attri *et al.*, 2013, adap.)

ISM can be developed and calculated by statistical software such as SPSS and Matlab, and its application steps are as follows:

Step 1: Identify the research question and system elements. First, we identify the issue and the target system that we want to study using the ISM, then we analyze the elements in the target system that are closely related to the research problem by dividing and disassembling the target system, and determine the final list of system elements.

Step 2: Establish contextual relationship between elements. After obtaining the system elements, we need to study and judge the association relationship between the system elements (*e.g.*, if element *A* can influence element *B*, the relationship from *A* to *B* can be established). The judgment process can be based on the logical relationship within the system or the experience that can be learned, which provides the basis for the subsequent research.

Step 3: Develop adjacency matrix. The adjacency matrix $L=L_{n*n}$ is a structural self-interaction matrix (SSIM) (Kannan, Pokharel, & Kumar, 2009). It is established based on the association of system elements, where n is the number of identified elements, so the value of L_{ij} is used to indicate whether there is an association between system elements according to equation (1):

$$L_{ij} = \begin{cases} 0, \text{i and j are unrelated} \\ 1, \text{i has effect on j} \end{cases} \tag{1}$$

Step 4: Develop the reachability matrix (RM) based on adjacency matrix *L*. The RM expresses whether two elements are reachable (*i.e.*, whether there is a direct or indirect influence relationship between the elements). As shown in *Figure 3.2*, there is a direct influence relationship between elements *A* and *B*, and an indirect influence relationship between elements *A* and *C* (Dubey & Ali, 2014). Therefore, element *A* can reach *B* and *C*.

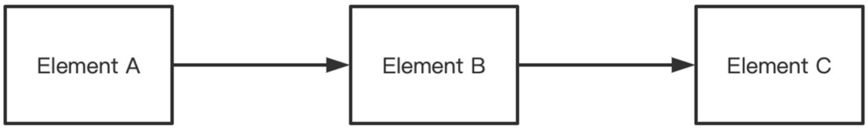


Figure 3.2. Schematic diagram of indirect influence.

(Source: Saxena & Vrat, 1990, adap.)

In the reachability matrix, R_{ij} is used to indicate whether the two elements are reachable, as shown equation (2):

$$R_{ij} = \begin{cases} 0, \text{i cannot achieve j} \\ 1, \text{i can achieve j} \end{cases}. \tag{2}$$

Step 5: Level partitions. The level structure of the system is obtained by cyclically solving the intersection of the reachability and prior matrix. If e_i denotes the i^{th} element, then all elements in the reachability set can be reached by element *P£*. The prior set is the set of all elements that can be reached by e_i. The specific solution process is to first solve reachability set R(e_i) and prior set $A(e_i)$ based on the RM, then solve the intersection of the reachable set and the prior set of each element $R(e_i)\cap A(e_i)$, respectively, and, finally, identify the level partitions where element e_i is located.

Step 6: Develop digraph and the ISM model. Draw the ISM diagram of the system based on the hierarchical structure and the correlations between the elements.

Along with the ISM, MICMAC analysis also serves a role in research. MICMAC analysis, first developed in 1970s, refers to *Matrice d'Impacts Croisés Multiplication Appliquée à un Classement* (Hussain, 2011). It is a system of multiplication of matrices applied to structural analysis with indirect inter-relationship (Duperrin & Godet, 1973). Researchers can observe three variables and their direct effects in indirect relationships: variable X affects Y, variable Y affects Z, and X and Z have no direct effect, but they have an inter-relationship with Y, where changes in X affect Z. This analysis is also known as a gray area exploration (Dubey & Ali, 2014). The method, as a combination tool with ISM, is suitable to conduct following sets of research: (1) discover relationships between the challenges; (2) classify challenges per their driving-dependence power; and (3) develop a hierarchical structural model among the challenges (Janssen, Luthra, Mangla, Rana, & Dwivedi, 2019). For years, researchers have adopted ISM-MICMAC approach to cultivate essential factors and structural systems in understanding multiple issues (*e.g.*, Dewangan, Agrawal, & Sharma, 2015; Dubey & Ali, 2014; Mangla, Madaan, & Chan, 2013). The approach is also well-deployed in managerial research throughout the healthcare industry (Kumar, Dhillon, Singh, & Sindhwani, 2019; Kumar & Sharma, 2018; Rathi, Kaswan, Antony, Cross, Garza-Reyes, & Furterer, 2022). A primary goal of MICMAC analysis is to inspect and segment the variables in terms of driving power and dependencies (Mandal, & Deshmukh, 1994), and categorize them into four sections. The first quadrant includes autonomous factors, which have neither high dependencies nor high drivers.

The second quadrant presents dependent factors, which have high dependence and low driving force. The third quadrant presents the linkage factors or relay variables, which have high dependence and driving power. The fourth quadrant includes independent factors or influence variables with low dependence and high driving force (Agrawal, 2019). As explained in the next section, the above methods will contribute valuable tools to the exploration of this study.

3.3. Possible Contributions to Hospital Planning and Resilience

The prominence of hospital resilience management and building in response to unexpected health-related events is increasingly highlighted. Therefore, the exploration of this topic requires the articulation of crucial influencing elements and their interactions. A more effective approach is structuring models that integrate multiple variables. Group decision-making, especially NGT, generates many thoughts and affords closure, often not witnessed in poorly structured group approaches (Stech & Ratliffe, 1985). It gives the possibility to collect and discuss experts' theoretical knowledge and substantive experience and, in doing so, perform the task of identifying and assessing determinants in the system and provide the basis for model building.

ISM technique is employed to explore the hierarchical relationship between complex elements with the advantage of robust structuring. It allows for action or policy analysis that assists participants in identifying specific areas of policy action that have strengths or leverage in pursuing specific goals (Attri *et al.*, 2013). This study is concerned with enhancing hospital resilience and planning capacity, which requires identifying structural features between variables. It is thus applicable to adopt this systematic approach. Upon the factors obtained in the previous step, the experts will negotiate a consensus to identify the influence relationships between the variables and create a matrix. The researcher can carry out extrapolation calculations on the matrix data to derive the hierarchical division between determinants and the direction of influence. Meanwhile, MICMAC analysis helps evaluate the role played by the elements in the system to clarify how to optimize the outcome. Overall, the ISM-MICMAC analysis method can clarify and visualize the component relationships and functional impacts of hospital resilience and ultimately provide guidance for improving hospital management practices. This study will proceed to the empirical research phase upon determining the methodology. The related contents are presented in *Chapter 4*.

SYNOPSIS OF CHAPTER 3

Chapter 3 explains the approaches used in this study. Group decision-making examines how each group member's preferences for a particular class of things can be aggregated into a group preference so that the group can rank or choose among all such objects. As a vehicle for making choices, this approach is a potent tool for addressing major qualitative decision-making problems. Among them, the NGT presents group members' views based on individual decisions and is able to prompt the expression of opinions in compliance with a structural framework. Present evidence suggests that group size and membership can significantly influence a study's development. In this study, the researcher will invite 6-10 experts with diversified backgrounds in hospital management, including academics, hospital managers, clinical practitioners, and hospital engineers, to constitute an expert panel. The panel will hold an online session, relying on its members' theoretical knowledge and practical experience, to propose and rationalize the factors affecting hospital resilience and planning capacity. ISM is a research method in systems science that effectively bridges the gap between the natural and social sciences. ISM modeling requires Boolean matrix operations or relatively complex topological analyses, typical of systems science. However, the interpretation of specific nodes and directed edges, these analytical processes belong to the social sciences. This study will be carried out with a facilitator-led discussion in which experts will point out the relationships between various influencing elements. These data will be calculated by the researcher into an adjacency matrix, followed by the calculation of the IRM, and then several iterations to create the FRM. Based on the FRM results, the study will eventually build the ISM model structure and identify the influence relationships between key variables. As a tool for analyzing elemental driving and dependencies power, the MICMAC approach will help explain the elemental nature of different determinants and understand the methodological structure and pathways for hospital planning and resilience in intensive crisis situations. *Chapter 4* will describe the primary process of this study and explore the findings.

CHAPTER 4

RESULTS AND ANALYSIS

After introducing the methodology in the previous section, this chapter organizes the process of studying the factors influencing hospital resilience and planning capacity in accordance with the relevant methodological specifications and procedures. Based on this, a structured and flat inquiry platform was created using a Group Decision Making approach to capture the elements to conduct ISM and MICMAC analyses. This section analyzes and explains the model to further explore the hierarchical relationships among the influencing factors and suggest substantive improvements. Finally, the consolidation session evaluates and comments on the feasibility and applicability to the result model of this study.

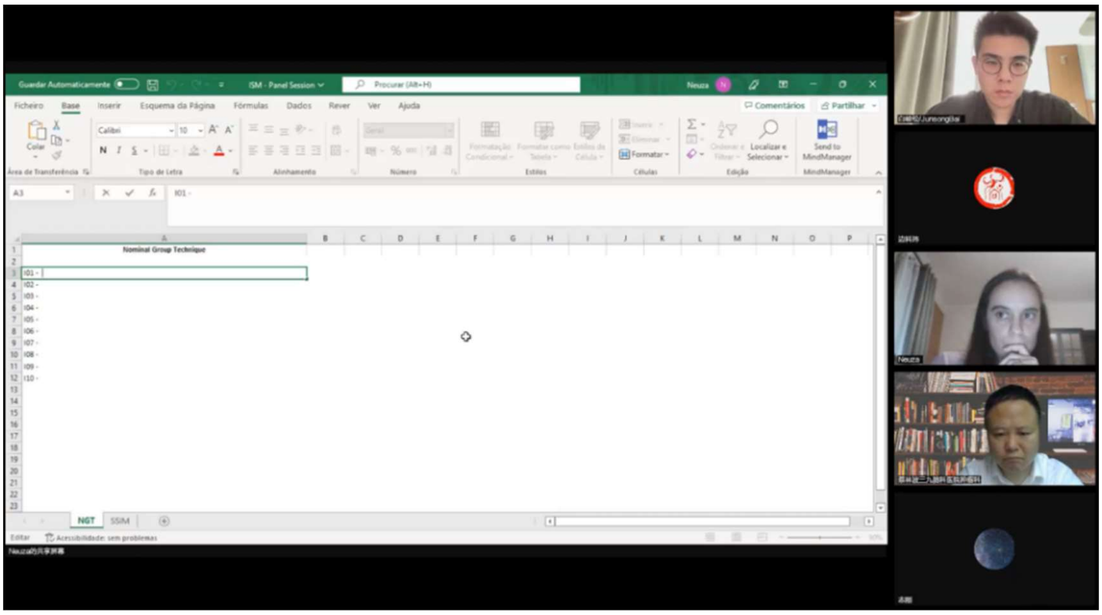
4.1. Hospital Resilience Determining Factors

By the methodology presented in *Chapter 3*, the main factors that strengthen hospital resilience and planning capacity can be derived through GDM. This approach enables the extraction and utilization of the professional experiences, knowledge, and perceptions of the different members of the discussion group, representing a larger and more diverse set of perspectives, constituencies, etc. (Tindale, Kameda, & Hinsz, 2003).

To achieve GDM, an expert panel was set up in this study to design the interview framework according to the requirements of ISM. Salmeron (2009) suggested that an expert panel should consist of five to eighteen members. Accordingly, the expert panel of this study invited a total of eight experts with extensive experience in related fields: (1) a professor and doctoral supervisor in healthcare management at a top university from Shanghai, China; (2) a manager, professor and master’s supervisor of a tertiary level A hospital from Shanghai; (3) another manager, professor, and master’s supervisor of a tertiary level A hospital from

Shanghai; (4) a director of oncology department and a vice-president of a specialized hospital, a university professor and master's supervisor from Guangzhou; (5) a deputy director of a prefecture-level health commission from northern China; (6) a chief of disease prevention and control section of a prefecture-level health commission from northern China; (7) an engineer with above 20 years of experience in medical architectural design and construction; (8) an associate professor and master’s degree supervisor of health management from a medical university, an expert in hospital emergency management.

The expert panel meeting was held on the 29th of October 2022. The panel members were located in different provinces and cities in China, while a professor familiar with ISM was assisting and recording in Portugal. Due to the distance and the fact that Covid-19 in China was still in the control phase, the expert panel was online using the Tencent Meeting and Voov Meeting platforms. The authors of this study moderated the proceedings and discussions throughout the session. The meeting began with a basic introduction to the base concepts related to hospital resilience and planning capacity and the methodology used in this study before formally launching the discussions. The first phase of the session consisted of presenting determinants by the panelists based on their expertise and experience. The second phase of the panel explored the impact relationships between the determinants. *Figure 4.1* presents a moment of the expert panel session.



Nominal Group Technique

I01 -
I02 -
I03 -
I04 -
I05 -
I06 -
I07 -
I08 -
I09 -
I10 -

Figure 4.1. The first phase of expert panel session.

The first phase of the session is to define determinants of enhancing hospital resilience and planning capacity, using nominal group and multi-voting techniques. At the beginning of the discussion, the moderator asked the panelists: *"Based on your experience and expertise, please suggest factors that influence the hospital's resilience and planning capacity"*. 8 panel members then presented what they considered essential determinants on the subject, which were recorded and organized remotely using Excel by the professor involved in the facilitation. After a round of presenting their ideas, the panel members came up with 22 influencing factors. However, for the requirement of ISM modeling, the moderator inserted a voting session on the influencing factors in the Tencent Meeting platform to condense the factors to elementary determinants. Each expert selected the 10 determinants that they considered the most essential and representative for the subsequent discussion and analysis of the interrelationship. Finally, as shown in *Table 4.1*, a total of 10 determinants were identified by the expert panel voting.

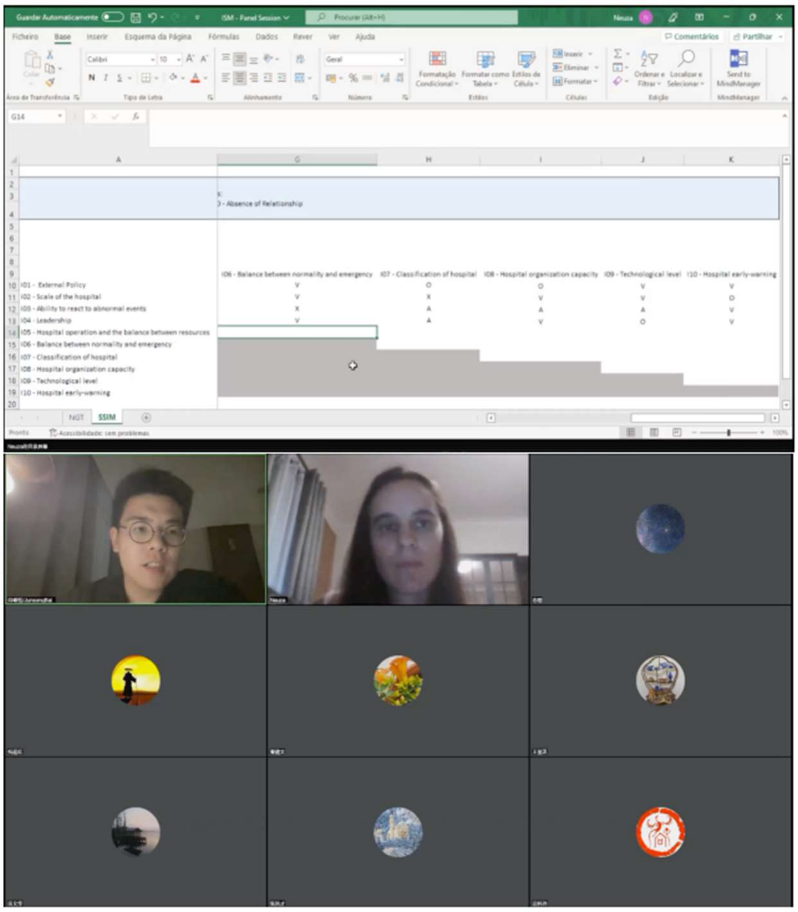
Table 4.1. Determinants identified by the expert panel session.

Code	Determinants
IN01	External Policy
IN02	Scale of the hospital
IN03	Ability to react to abnormal events
IN04	Leadership
IN05	Hospital operation and the balance between resources
IN06	Balance between normality and emergency
IN07	Classification of a hospital
IN08	Hospital organizational capacity
IN09	Technological level
IN10	Hospital early-warning

4.2. ISM Application

Proceeding from the 10 determining factors identified in the first phase, the second phase of the expert panel applied the ISM technique to measure the relationships between them. *"The ISM process transforms unclear, poorly articulated mental models of systems into visible, well-*

defined models useful for many purposes" (Raut, Narkhede, & Gardas, 2017, p. 37). During the session, the panel constructed the Structural Self-Interaction Matrix (SSIM) for exploring and documenting the experts' consensus on inter-relationships between determinants. Based on the 10 determinants identified in the first phase, the second phase of the expert panel applied the ISM technique to measure the relationships between the determinants. The panel had to choose a contextual relationship that "causes" or "affects", meaning that one factor influences the other. In this process, the contextual relationships between the factors are identified (Attri *et al.*, 2013). *Figure 4.2* presents the second phase of the session.



- Absence of Relationship

	I06 - Balance between normality and emergency	I07 - Classification of hospital	I08 - Hospital organization capacity	I09 - Technological level	I10 - Hospital early-warning
I01 - External Policy	V	O	O	V	V
I02 - Scale of the hospital	V	X	V	V	O
I03 - Ability to react to abnormal events	X	A	A	A	V
I04 - Leadership	V	A	V	O	V
I05 - Hospital operation and the balance between resources					
I06 - Balance between normality and emergency					
I07 - Classification of hospital					
I08 - Hospital organization capacity					
I09 - Technological level					
I10 - Hospital early-warning					

Figure 4.2. The second phase of expert panel session.

The moderator introduced the methodology to study the relationship between the different determinants. The session first coded 10 factors using I01 to I10 and recorded them in an Excel sheet in rows and columns to develop a matrix, namely Structural Self-Interaction Matrix (SSIM). In SSIM, one-to-one correspondence is formed between the elements (*i.e.*, cells in the table). These are used to explore and record the consensus from the experts' subsequent discussions on the relationship between determinants. According to the ISM approach, there are 4 categories of relationships between variables (IN_i, IN_j) symbolized with V, A, X, and O. Their meanings are explained in *Table 4.2*.

Table 4.2. The contextual relationship of determinants.

Symbol	**Meaning**
V	IN_i has direct influence on IN_j
A	IN_j has inverse influence on IN_i
X	IN_i and IN_j have bi-directional influence on each other
O	IN_i and IN_j are not related

During the second phase, experts analyzed and shared knowledge about each set of contextual relationships one by one and finally reached relatively consistent conclusions, which were then organized in SSIM by the professor who assisted in the documentation. *Table 4.3* represents the SSIM identified by the penal members.

Table 4.3. The Structural Self-Interaction Matrix (SSIM) identified.

	IN01	IN02	IN03	IN04	IN05	IN06	IN07	IN08	IN09	IN10
IN01		O	V	O	V	V	O	O	V	V
IN02			V	O	V	V	X	V	V	O
IN03				A	A	X	A	A	A	V
IN04					V	V	A	V	O	V
IN05						V	A	A	O	O
IN06							O	A	A	A
IN07								V	V	O
IN08									O	V
IN09										O
IN10										

The expert panel concluded after the completion of SSIM development. As introduced by ISM *Step 3* in *Chapter 3*, this study then constructs a binary matrix, namely the Initial

Reachability Matrix (IRM), based on SSIM. The result of calculation is shown as *Table 4.4*. The calculation of this matrix follows the specifications below:

(1) If the symbol of (IN_i, IN_j) in SSIM is V, then (IN_i, IN_j) in the reachability matrix becomes 1, and (IN_j, IN_i) becomes 0.

(2) If the symbol of (IN_i, IN_j) in SSIM is A, then (IN_i, IN_j) in the reachability matrix becomes 0, and (IN_j, IN_i) becomes 1.

(3) If the symbol of (IN_i, IN_j) in SSIM is X, then (IN_i, IN_j) in the reachability matrix becomes 1, and (IN_j, IN_i) also becomes 1.

(4) If the symbol of (IN_i, IN_j) in SSIM is O, then (IN_i, IN_j) in the reachability matrix becomes 0, and (IN_j, IN_i) also becomes 0.

Table 4.4. Developing the Initial Reachability Matrix (IRM).

	IN01	IN02	IN03	IN04	IN05	IN06	IN07	IN08	IN09	IN10
IN01	1	0	1	0	1	1	0	0	1	1
IN02	0	1	1	0	1	1	1	1	1	0
IN03	0	0	1	0	0	1	0	0	0	1
IN04	0	0	1	1	1	1	0	1	0	1
IN05	0	0	1	0	1	1	0	0	0	0
IN06	0	0	1	0	0	1	0	0	0	0
IN07	0	1	1	1	1	0	1	1	1	0
IN08	0	0	1	0	1	1	0	1	0	1
IN09	0	0	1	0	0	1	0	0	1	0
IN10	0	0	0	0	0	1	0	0	0	1

After performing transitivity analysis for each variable in the IRM, the results of each determinant are manually integrated into a new matrix to form the Final Reachability Matrix (FRM), which is shown in *Table 4.5*. Those “1s” marked with an “*” are the items that were “0” in IRM before. The detailed process of transitivity analysis to IRM is also presented in *Appendix Table 1* to *Table 11*.

Table 4.5. Developing the Final Reachability Matrix (FRM).

	IN01	IN02	IN03	IN04	IN05	IN06	IN07	IN08	IN09	IN10	**Dr Pw**
IN01	1	0	1	0	1	1	0	0	1	1	6
IN02	0	1	1	1*	1	1	1	1	1	1*	9
IN03	0	0	1	0	0	1	0	0	0	1	3
IN04	0	0	1	1	1	1	0	1	0	1	6
IN05	0	0	1	0	1	1	0	0	0	1*	4
IN06	0	0	1	0	0	1	0	0	0	1*	3
IN07	0	1	1	1	1	1*	1	1	1	1*	9
IN08	0	0	1	0	1	1	0	1	0	1	5
IN09	0	0	1	0	0	1	0	0	1	1*	4
IN10	0	0	1*	0	0	1	0	0	0	1	3
Dp Pw	1	2	10	3	6	10	2	4	4	10	

In partition analysis, the Reachability Set for each hospital resilience and planning capacity determinant is read from the vertical relationship of FRM, and the Antecedent Set is read in the horizontal connection. The Reachability Set includes the variable itself and the determinants it influences, while the Antecedent Set includes the variable itself and the impacted initiatives. Level 1 variables represent the highest level of structure and do not influence other factors (Kannan & Haq, 2007). By analogy, level *n* uses data from the intersection set, excluding factors from the previous level, and these levels help develop the final ISM model (Singh & Kant, 2008). This study completed the level partition process for all 10 determinants in 5 iterations, as shown in *Table 4.6* to *Table 4.10*.

Table 4.6. Level partitioning of FRM – Iteration 1.

	Reachability Set	Antecedent Set	Intersection Set	Level
IN01	1-3-5-6-9-10	1	1	--
IN02	2-3-4-5-6-7-8-9-10	2-7	2-7	--
IN03	3-6-10	1-2-3-4-5-6-7-8-9-10	3-6-10	1
IN04	3-4-5-6-8-10	2-4-7	4	--
IN05	3-5-6-10	1-2-4-5-7-8	5	--
IN06	3-6-10	1-2-3-4-5-6-7-8-9-10	3-6-10	1
IN07	2-3-4-5-6-7-8-9-10	2-7	2-7	--
IN08	3-5-6-8-10	2-4-7-8	8	--
IN09	3-6-9-10	1-2-7-9	9	--
IN10	3-6-10	1-2-3-4-5-6-7-8-9-10	3-6-10	1

Table 4.7. Level partitioning of FRM – Iteration 2.

	Reachability Set	Antecedent Set	Intersection Set	Level
IN01	1-5-9	1	1	--
IN02	2-4-5-7-8-9	2-7	2-7	--
IN04	4-5-8	2-4-7	4	--
IN05	5	1-2-4-5-7-8	5	2
IN07	2-4-5-7-8-9	2-7	2-7	--
IN08	5-8	2-4-7-8	8	--
IN09	9	1-2-7-9	9	2

Table 4.8. Level partitioning of FRM – Iteration 3.

	Reachability Set	Antecedent Set	Intersection Set	Level
IN01	1	1	1	3
IN02	2-4-7-8	2-7	2-7	--
IN04	4-8	2-4-7	4	--
IN07	2-4-7-8	2-7	2-7	--
IN08	8	2-4-7-8	8	3

Table 4.9. Level partitioning of FRM – Iteration 4.

	Reachability Set	Antecedent Set	Intersection Set	Level
IN02	2-4-7	2-7	2-7	--
IN04	4	2-4-7	4	4
IN07	2-4-7	2-7	2-7	--

Table 4.10. Level partitioning of FRM – Iteration 5.

	Reachability Set	Antecedent Set	Intersection Set	Level
IN02	2-7	2-7	2-7	5
IN07	2-7	2-7	2-7	5

A subsequent structural model derived from FRM was developed in this study. If there is a relationship between IN_i and IN_j, it is shown by an arrow that points from IN_i to IN_j, and the generated graph is called the initial directed graph or the initial digraph (Raut *et al.*, 2017). Upon eliminating the transitivity in the initial digraph, the final directed graph is formed as shown in *Figure 4.3*. The completed ISM model is presented in *Figure 4.5* by replacing the code with determinants.

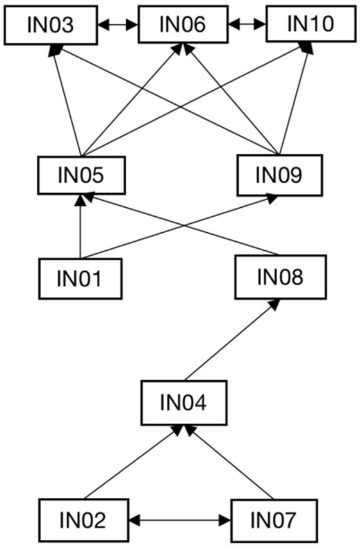


Figure 4.3. Final ISM model derived from FRM.

MICMAC classifies variables into four quadrants according to the difference between driving and dependence power: I – Autonomous; II – Dependent; III – Linkage; and IV – Dependent (Janssen *et al.*, 2019). To calculate the driving and dependent power for each determinant, this study uses the sum of rows and columns from the FRM to perform and conducts the MICMAC analysis in *Table 4.7*.

Table 4.11. Conducting the MICMAC analysis.

	Dp Pw (x)	**Dr Pw (y)**	**Type**	**Quadrant**
IN01	1	6	Independent	IV
IN02	2	9	Independent	IV
IN03	10	3	Dependent	II
IN04	3	6	Independent	IV
IN05	6	4	Dependent	II
IN06	10	3	Dependent	II
IN07	2	9	Independent	IV
IN08	4	5	Autonomous	I
IN09	4	4	Autonomous	I
IN10	10	3	Dependent	II

At this point, the empirical process of this study has been concluded. The following section will offer a focused discussion of the results.

4.3. Discussion of Results

Healthcare is a dynamic system with disruptive effects of failure exacerbated by the occurrence of diverse elements (Woods, Johannesen, Cook, & Sarter, 1994). The crises and emergencies that hospitals are called upon to face are of considerable complexity and uncertainty. It is strategically important to clarify the relationships among the associated elements and the pivotal entry points for strengthening hospital resilience. Consequently, this study conducted literature research, carried out GDM, and included 10 critical determinants to analyze and discover the ISM model for enhancing hospital resilience, resulting in a structural hierarchy (see *Figure 4.4*).

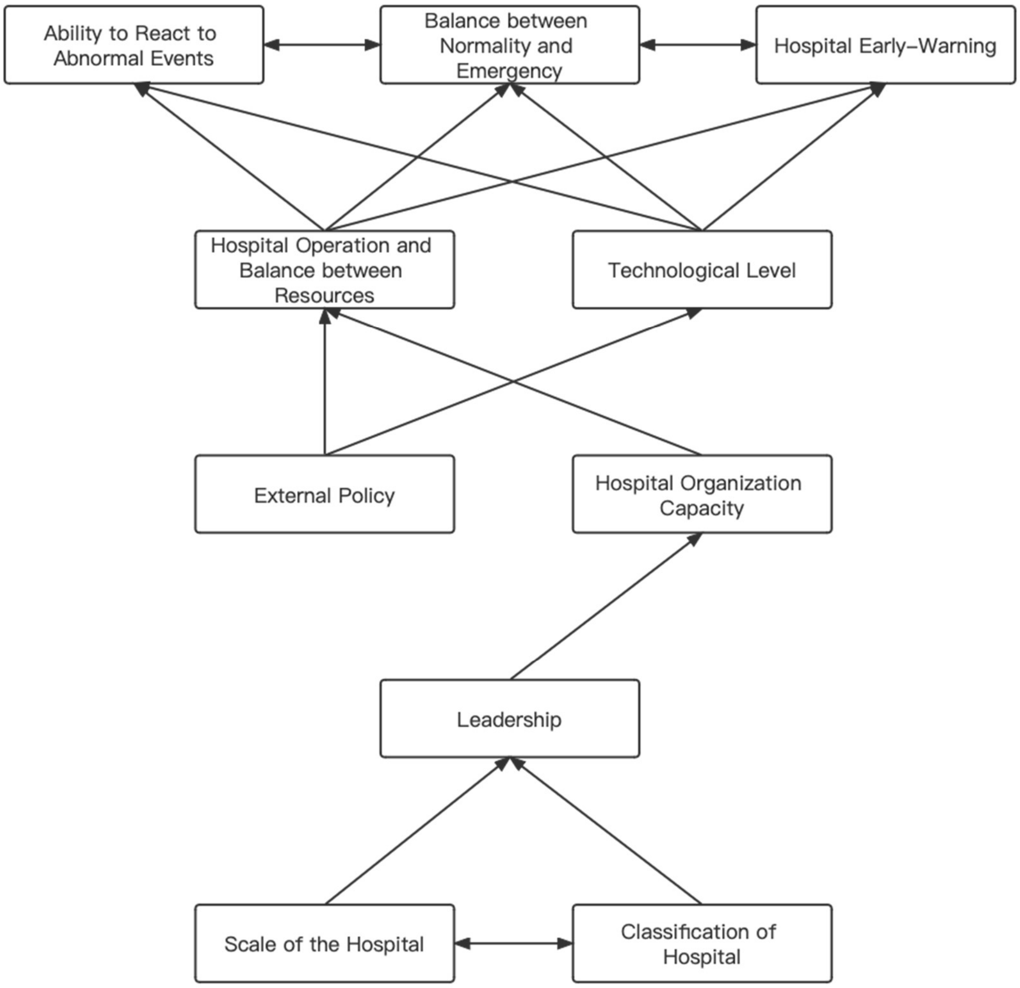


Figure 4.4. ISM of enhancing hospital resilience and planning capacity

The first three determinants of the model, IN03 – Ability to react to Abnormal Events, IN06 – Balance between Normality and Emergency, and IN10 – Hospital Early-Warning are thought to exert the most direct influence. The researchers believe these elements are closer to hospital resilience's performance and evaluation elements. Therefore, they should benefit from more immediate consideration to improve the managerial pathway of hospital resilience.

The second layer of elements includes IN05 – Hospital operation and balance between resources and IN09 – Technological level, which plays comparatively connecting roles in their ability to impact and importance. The third level of the model (*i.e.*, IN01 – External policy and IN08 – Hospital organizational capacity), followed by the fourth level (*i.e.*, IN04 – Leadership) has the potential to influence the drivers of the top categories and deserves to be emphasized in the development of hospital resilience management practices. In the final iteration, two determinants significantly influence the middle and top tiers. They need utmost priority and development, respectively, IN02 – Scale of hospital and IN07 – Classification of hospital. Where again, *Figure 4.5* illustrates that the Scale and Classification are critical to achieving Leadership and contribute to the further attainment of Hospital organizational capacity.

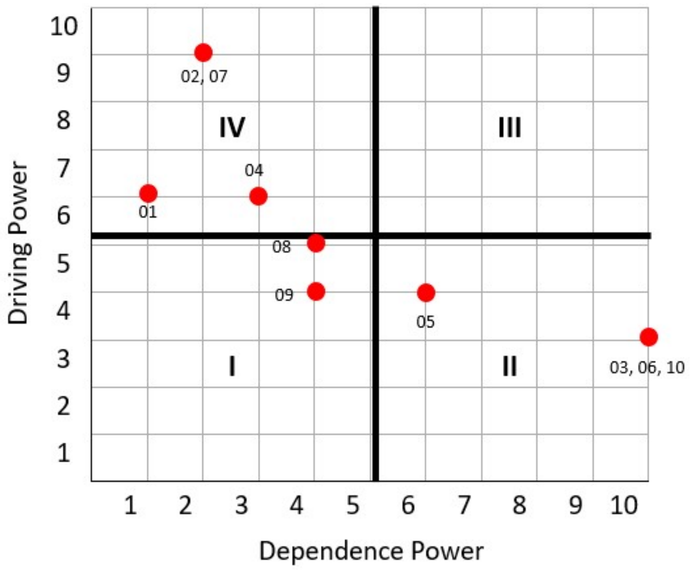


Figure 4.5. MICMAC analysis for ISM determinants.

In MICMAC analysis, all determinants are divided into 4 clusters/quadrants. The values of each determinant in the above results (*Table 4.7*) mark correspondingly into the MICMAC coordinate system to obtain the diagram demonstrated in *Figure 4.5*. Interpretations are as follows:

(1) Cluster I – Autonomous quadrant includes Hospital organization capacity and Technological level. These are factors with weak dependence and driving power, suggesting that they have a comparatively minor direct impact on hospital resilience.

(2) Cluster II – Dependent quadrant includes Ability to react to abnormal events, Hospital operation and the balance between resources, Balance between normality and emergency, and Hospital early-warning. These elements are strongly dependent and pose weak driving power. These four components are at the cascade top of the ISM hierarchy. As such, hospital decision-makers prioritize reinforcing relevant competencies and should address the issues related to these practices as a matter of urgency.

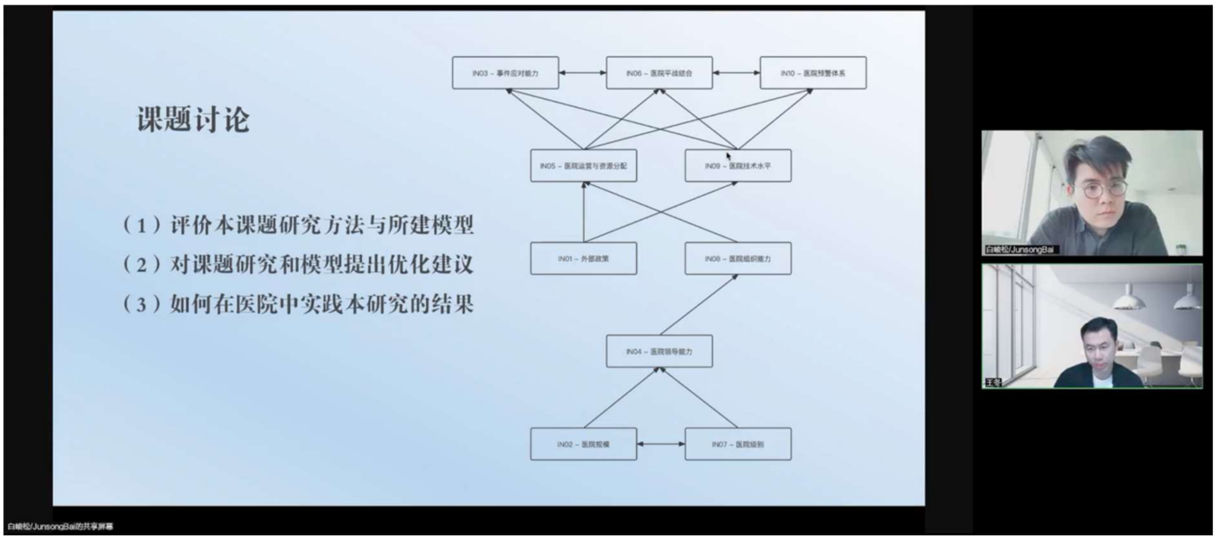
(3) Cluster III – Linkage quadrant possesses no element.

(4) Cluster IV – Independent quadrant includes External Policy, Scale of the hospital, Leadership, and Classification of hospital. They have strong driving power and less dependency, and are at the fundamental levels of the hierarchical model. Accordingly, hospital decision-makers are expected to address these elements with greater precision in their management practices enhancing hospital resilience and planning capacity. In addition, these determinants advance practice, and practice outcomes are at the top of the ISM model structure. Thus, managers' concentration and deployment of these four elements can help improve hospital emergency response, normality-emergency balance, and early warning capacity building. In the next section, the above-obtained findings will be discussed with external neutral experts.

4.4. Consolidation of Results, Limitations, and Recommendations

This study explores and analyzes the elements enhancing hospital resilience and planning capacity and clarifies their qualitative hierarchical relationships through an interpretative structural model. The obtained results identify and highlight the fundamental factors which are of reference value for hospital management practice.

Having yielded the results, the researcher invited the Dean of the School of Health Management of Southern Medical University to conduct an online consolidation session in March 2023 to investigate further and optimize the study. Since this expert did not participate in the expert panel, he had a neutral position as an external member, which helped to provide an objective professional opinion about the study. The session lasted about 30 minutes. First, the researcher introduced the key concepts and background and presented and presented the methodology and results. *Figure 4.6* shows a screenshot of this session.



课题讨论

（1）评价本课题研究方法与所建模型

（2）对课题研究和模型提出优化建议

（3）如何在医院中实践本研究的结果

Figure 4.6. Study Consolidation Session

After a brief introduction, the experts commented on the methods and results of this study. First, the topic of this study is valuable, especially in the context of the immediate end of the Covid-19 pandemic, and it is highly relevant to reflect on the establishment of hospital resilience. Secondly, the ISM method adopted in this study could coalesce expert consensus, analyze critical elements, and obtain holistic hierarchical results with a scientific and rigorous approach.

However, there are still some shortcomings that need to be optimized. First, in the current model, there may be synergy between elements or unclear conceptual boundaries, which affects the identification of management elements in practice and needs to be clarified through further research. Second, the current model is mainly qualitative, and to define the level of significant effects among variables, quantitative relationships need to be calculated by more studies such as questionnaires. Third, although the experts in this study have a diversity of expertise and background, the interview sample is limited, the representativeness of the results is still inadequate, and the scope of the research can be expanded in different hospitals with this model. In this regard, it is worth noting that this study is process-oriented. As such, the objective of this study was not representativeness—nor the ability to form generalizations—; rather, there was a strong focus on process. As Bell and Morse (2013, p. 962) explain, *“there is less emphasis on outputs per se and more focus on process”*. Fourth, the study may apply relevant theoretical models to enhance the credibility and scientificity of the model. Moreover, it is challenging to implement and test this model in hospitals due to the acceptance of hospital managers, the complexity of hospital operations, and the substantial uncertainty of the emergence of crises. However, the researcher can conduct in-depth studies in hospitals and compare hospitals that emphasize the critical variables of this model with others to develop a retrospective cohort to verify the model outcome of this study.

So far, all the results of this study have been derived and discussed. The researcher hopes to use this as a rationale to inform realistic hospital management. Relevant practice recommendations will be presented in the next chapter.

SYNOPSIS OF CHAPTER 4

Chapter 4 presents the empirical research process and results. With methodologies presented in *Chapter 3*, this section identifies the factors that enhance hospital resilience and planning capacity and explores their contextual relationships. This panel consisted of eight experts with diverse backgrounds in hospital resilience management, including hospital managers, clinicians, academics, and engineers. In the first part of the session, the members identified ten determinants through a nominal group technique and a multivariate voting method. The second part of the workshop then synthesized multiple views and discussed under the ISM framework to reach a consensus on the relationships between the elements, creating the Structural Self-Interaction Matrix (SSIM). Following the expert panel, this study extrapolates and analyzes the results using the ISM method. First, the SSIM results obtained at the session were transformed into Initial Reachability Matrix (IRM) using the binary method in this paper. Secondly, transitivity analysis processed the data from IRM, transformed each variable, and generated the Final Reachability Matrix (FRM). It is used to construct the ISM model. Subsequently, this study performed level partitioning on the variables in the FRM, and after five iterations, the hierarchy among the variables was derived. In the construction phase, the researcher designed the structure of the ISM model by iteration results and then determined the influence relationship between different variables by FRM, which finally resulted in the model shown in *Figure 4.3*. The data of the ISM framework also proceeded to MICMAC analysis. The researcher extracted the parameters of FRM and positioned the variables into four quadrants by driving and dependence power. Ultimately, among the ten determinants, Autonomous section had two, Dependent section had four, and Driver section also had four. The study then discussed the applicability of the model results with external experts. The expert panel members in this study were all from China, and most with public hospital backgrounds. It may yield new findings in other regions and contexts. Yet, the methodology used in this study is promising and could carry out on other topics regarding hospital management. *Chapter 5* will summarize this study, propose implications for management practice, and outline potential research directions.

CHAPTER 5

CONCLUSION

5.1. Main Results

Discovering the factors underlying and optimizing pathways for strengthening hospital resilience and planning capacity is quite complex. One is that resilience is a quality that is difficult to measure straightforwardly. The other is that professionals and managers with ample practice experience retain subjectivity in their observations, making it difficult to reach a single consistent conclusion in research. As a result, a structured model that integrates multiple factors becomes an effective solution for exploring this topic. With this as a starting point, this study designed and developed a hierarchical model to support the build-up of hospital resilience.

This dissertation follows rigorous academic logic and comprises five chapters. In *Chapter 1* – Introduction, the paper briefly describes the research background, objectives, methodology, and content structure. *Chapter 2* – Literature Review starts by exploring the key concepts, reviewing the theoretical models in the published papers, and on this basis, identifying the limitations and evolving space of the existing studies. *Chapter 3* – methodology compares the main methods employed in this study, including group decision-making, ISM model, and MICMAC analysis. After implementing the tools above into research practice, *Chapter 4* – Results and Discussion presents the process and outcomes of the empirical findings, identifies the key determinants in the context of this study, constructs a hierarchical ISM model, and ultimately provides an impact system and an optimization path. *Chapter 5* – Conclusion summarizes the overall study, suggests possible managerial implications, and states the study's contributions, limitations, and potential research directions.

A hierarchical model was established with an ISM approach, incorporating crucial decision elements, to study their connection between the impact of enhancing hospital resilience and planning capacity. MICMAC was also deployed to analyze how the elements interact with the system. In the nominal group session, experts supported and exchanged their expertise and industry experience, neutralizing the subjective selection of personal preferences and allowing the study to draw vital intellectual insights from the discussion. After the discussions yielded determinants, the study synthesized the experts' reflections on relevant implications and extrapolated the interactions among elements from SSIM to FRM. These efforts resulted in the ISM model, which was validated and appraised by an external scholar and policymaker.

Hence, according to the model output, the first level, IN03 – Ability to react to Abnormal Events, IN06 – Balance between Normality and Emergency, and IN10 – Hospital Early-Warning, along with the second level, IN05 – Hospital operation and balance between resources and IN09 – Technological level, which are at the top of the hierarchy, most directly affect and reflect the hospital resilience, and have a strong operability. The MICMAC analysis also highlights most of these variables, indicating they occupy strong depending power. The third level, IN01 – External policy and IN08 – Hospital organizational capacity and the fourth level, IN04 – Leadership reach into the key aspects affecting hospital resilience, serving as an essential element in affecting the variables in the top structure, and managers have a more profound role to play in this part in the fifth level of the model, IN02 – Scale of hospital and IN07 – Classification Scale of hospital have the capacity to exert influence on the underlying logic. Among them, IN02, IN07, IN01, IN04 have high driving power, which require the most significant consideration form the decision-makers.

5.2. Managerial Implications for Hospital Planning

Hospital executives should prioritize the advancement of balance between normality and emergency, the ability of emergency reaction, early warning, and daily operations. They have the most immediate impact on hospital resilience and can also be the measures of hospital resilience at a certain level. The findings of this section match the theories of previous studies, and it is evident that the results of this study have some indicative value and that managers can carry out a quantitative rating scheme on these elements to set worthwhile goals for strengthening planning capacity. Moreover, these determinants belong to the dependent quadrant in the study's MICMAC analysis, suggesting a profound and underlying chain of influence behind them.

Integrating the ISM model (*Figure 4.4*) and the variables with high driving power (*Figure 4.5*) derived from this study, it is suggested that the following categories of variables start at the fundamental level and cascade upward, ultimately yielding a critical effect on hospital resilience. These variables include hospital scale, classification, leadership, and external policy.

The greater the size of a hospital, the more likely it is to have well-rounded departments with adequate medical staff, and better satisfy patients' needs (McFarland, Shen, Parker, Meyerson, & Holcombe, 2017). Large and healthily operating hospitals have a more robust capacity to handle emergencies while allowing for dynamic optimization of space in response to real-world medical need changes, creating greater infrastructure design capacity and flexibility (Neufville, Lee, & Scholtes, 2008). Therefore, managers should develop hospital size. Nevertheless, this study also believes that over-emphasizing the scale will increase operational difficulties and even lead to sloppy management issues, endangering the hospital itself. At the same time, the excessive scale will also create a significant siphoning effect on neighboring medical resources, which is not conducive to developing a hierarchical diagnosis and treatment system (Fu, Xu, Liu, Liang, & Wang, 2021), so scale expansion should be moderate. Hospital classification is likewise a fundamental element that is associated with scale. When the scale grows to a certain level, the hospital classification may improve, such as secondary hospitals becoming tertiary hospitals, especially for public hospitals, which implies higher resource allocations and talent attractiveness. However, because hospital classification entails serving local healthcare needs, it is constrained by systematic healthcare planning (Sun & Yin, 2018).

The leadership of hospital managers is extraordinarily vital, and the larger and higher the hospital level, the higher the competency required of the managers. Hospital executives with a higher voice impact organizational capacity and influence determinants at other levels of the ISM model. The hospital decision-maker should therefore have a clear organizational perspective and strategic vision to provide leadership support for strengthening hospital resilience. The external policy is fundamental in a planning capacity and is usually an administrative force outside of the hospital's control in various geographical levels (Jiang, Min, & Fang, 2017). It is significant in the hospital's operating model, clinical norms, and audit requirements. As shown in the ISM model, hospital operation and technological level are governed by the role of external policy. Therefore, hospital managers should monitor policy and administrative norms continuously and timely to ensure that hospitals are regulated concerning emergency management and resilience.

5.3. Lines for Future Research

Constrained by distinct conditions and subjective attributes, the present study has limitations. First, although the expert panel of this study included members from various subfields around hospital resilience management, given the consistency of the study target and the ease of communication, the experts were all from China. They also had a predominantly public hospital or institutional background. Consequently, the study's report and findings are aligned more with an internal perspective of the Chinese healthcare system. In addition, based on the general characteristics of Chinese hospitals that public hospitals are significantly outperformed by social capital healthcare providers (Eggleston, Lu, Li, Wang, Yang, Zhang, & Quan, 2010), this study also stands more on the viewpoint of public hospitals in the actual discussion. For instance, hospital classification affects the role of financial investment and, thus, other elements. The situation in private hospitals may differ. Therefore, the findings of this study are geographically and systematically limited, and there is an applicability uncertainty in other regions, and researchers from other backgrounds may come to different findings. This point is related to the constructivist and methodological basis of this study. However, the results of this study likewise provide a professional structural rationale that facilitates hospital administrators' understanding and practice of actions and pathways to enhance hospital resilience.

This paper controls the components incorporated in the ISM model construction and refines and compresses many other variables proposed by experts in the panel session. This process, on the one hand, facilitates the abstraction of a mutually applicable model, but on the other hand, it also leads to a macroscopic study of the determinants. Therefore, this study has some areas for improvement in exploring the internal rationale of each determinant and more specific elements. Besides, the present results concentrate on hospital management elements, while improving hospital resilience still calls for a comprehensive exploration from other perspectives. With this fact, subsequent research lines must delve into subtler spheres and relationships to compile a holistic and concrete structure.

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APPENDIX

Appendix – Conducting the Transitivity Analysis for Each Determinant

Table 1. Initial Reachability matrix used for Transitivity Analysis

	IN01	IN02	IN03	IN04	IN05	IN06	IN07	IN08	IN09	IN10
IN01	1	0	1	0	1	1	0	0	1	1
IN02	0	1	1	0	1	1	1	1	1	0
IN03	0	0	1	0	0	1	0	0	0	1
IN04	0	0	1	1	1	1	0	1	0	1
IN05	0	0	1	0	1	1	0	0	0	0
IN06	0	0	1	0	0	1	0	0	0	0
IN07	0	1	1	1	1	0	1	1	1	0
IN08	0	0	1	0	1	1	0	1	0	1
IN09	0	0	1	0	0	1	0	0	1	0
IN10	0	0	0	0	0	1	0	0	0	1

Table 2. Transitivity Analysis for IN01

	IN01	IN02	IN03	IN04	IN05	IN06	IN07	IN08	IN09	IN10
IN01	1	0	1	0	1	1	0	0	1	1
IN02	0	1	1	0	1	1	1	1	1	0
IN03	0	0	1	0	0	1	0	0	0	1
IN04	0	0	1	1	1	1	0	1	0	1
IN05	0	0	1	0	1	1	0	0	0	0
IN06	0	0	1	0	0	1	0	0	0	0
IN07	0	1	1	1	1	0	1	1	1	0
IN08	0	0	1	0	1	1	0	1	0	1
IN09	0	0	1	0	0	1	0	0	1	0
IN10	0	0	0	0	0	1	0	0	0	1
IN03	0	0	1	0	0	1	0	0	0	1
IN05	0	0	1	0	1	1	0	0	0	0
IN06	0	0	1	0	0	1	0	0	0	0
IN09	0	0	1	0	0	1	0	0	1	0
IN10	0	0	0	0	0	1	0	0	0	1
IN01	1	0	1	0	1	1	0	0	1	1

Table 3. Transitivity Analysis for IN02

	IN01	IN02	IN03	IN04	IN05	IN06	IN07	IN08	IN09	IN10
IN02	0	1	1	0	1	1	1	1	1	0

	IN01	IN02	IN03	IN04	IN05	IN06	IN07	IN08	IN09	IN10
IN01	1	0	1	0	1	1	0	0	1	1
IN03	0	0	1	0	0	1	0	0	0	1
IN04	0	0	1	1	1	1	0	1	0	1
IN05	0	0	1	0	1	1	0	0	0	0
IN06	0	0	1	0	0	1	0	0	0	0
IN07	0	1	1	1	1	0	1	1	1	0
IN08	0	0	1	0	1	1	0	1	0	1
IN09	0	0	1	0	0	1	0	0	1	0
IN10	0	0	0	0	0	1	0	0	0	1

	IN01	IN02	IN03	IN04	IN05	IN06	IN07	IN08	IN09	IN10
IN03	0	0	1	0	0	1	0	0	0	1
IN05	0	0	1	0	1	1	0	0	0	0
IN06	0	0	1	0	0	1	0	0	0	0
IN07	0	1	1	1	1	0	1	1	1	0
IN08	0	0	1	0	1	1	0	1	0	1
IN09	0	0	1	0	0	1	0	0	1	0

	IN01	IN02	IN03	IN04	IN05	IN06	IN07	IN08	IN09	IN10
IN02	0	1	1	1*	1	1	1	1	1	1*

Table 4. Transitivity Analysis for IN03

	IN01	IN02	IN03	IN04	IN05	IN06	IN07	IN08	IN09	IN10
IN03	0	0	1	0	0	1	0	0	0	1
IN01	1	0	1	0	1	1	0	0	1	1
IN02	0	1	1	0	1	1	1	1	1	0
IN04	0	0	1	1	1	1	0	1	0	1
IN05	0	0	1	0	1	1	0	0	0	0
IN06	0	0	1	0	0	1	0	0	0	0
IN07	0	1	1	1	1	0	1	1	1	0
IN08	0	0	1	0	1	1	0	1	0	1
IN09	0	0	1	0	0	1	0	0	1	0
IN10	0	0	0	0	0	1	0	0	0	1
IN06	0	0	1	0	0	1	0	0	0	0
IN10	0	0	0	0	0	1	0	0	0	1
IN03	0	0	1	0	0	1	0	0	0	1

Table 5. Transitivity Analysis for IN04

	IN01	IN02	IN03	IN04	IN05	IN06	IN07	IN08	IN09	IN10
IN04	0	0	1	1	1	1	0	1	0	1

IN01	1	0	1	0	1	1	0	0	1	1
IN02	0	1	1	0	1	1	1	1	1	0
IN03	0	0	1	0	0	1	0	0	0	1
IN05	0	0	1	0	1	1	0	0	0	0
IN06	0	0	1	0	0	1	0	0	0	0
IN07	0	1	1	1	1	0	1	1	1	0
IN08	0	0	1	0	1	1	0	1	0	1
IN09	0	0	1	0	0	1	0	0	1	0
IN10	0	0	0	0	0	1	0	0	0	1

IN03	0	0	1	0	0	1	0	0	0	1
IN05	0	0	1	0	1	1	0	0	0	0
IN06	0	0	1	0	0	1	0	0	0	0
IN08	0	0	1	0	1	1	0	1	0	1
IN10	0	0	0	0	0	1	0	0	0	1

IN04	0	0	1	1	1	1	0	1	0	1

Table 6. Transitivity Analysis for IN05

	IN01	IN02	IN03	IN04	IN05	IN06	IN07	IN08	IN09	IN10
IN05	0	0	1	0	1	1	0	0	0	0

IN01	1	0	1	0	1	1	0	0	1	1
IN02	0	1	1	0	1	1	1	1	1	0
IN03	0	0	1	0	0	1	0	0	0	1
IN04	0	0	1	1	1	1	0	1	0	1
IN06	0	0	1	0	0	1	0	0	0	0
IN07	0	1	1	1	1	0	1	1	1	0
IN08	0	0	1	0	1	1	0	1	0	1
IN09	0	0	1	0	0	1	0	0	1	0
IN10	0	0	0	0	0	1	0	0	0	1

IN03	0	0	1	0	0	1	0	0	0	1
IN06	0	0	1	0	0	1	0	0	0	0

IN05	0	0	1	0	1	1	0	0	0	1*

Table 7. Transitivity Analysis for IN06

	IN01	IN02	IN03	IN04	IN05	IN06	IN07	IN08	IN09	IN10
IN06	0	0	1	0	0	1	0	0	0	0

IN01	1	0	1	0	1	1	0	0	1	1
IN02	0	1	1	0	1	1	1	1	1	0
IN03	0	0	1	0	0	1	0	0	0	1
IN04	0	0	1	1	1	1	0	1	0	1
IN05	0	0	1	0	1	1	0	0	0	0
IN07	0	1	1	1	1	0	1	1	1	0
IN08	0	0	1	0	1	1	0	1	0	1
IN09	0	0	1	0	0	1	0	0	1	0
IN10	0	0	0	0	0	1	0	0	0	1

IN03	0	0	1	0	0	1	0	0	0	1

IN06	0	0	1	0	0	1	0	0	0	1*

Table 8. Transitivity Analysis for IN07

	IN01	IN02	IN03	IN04	IN05	IN06	IN07	IN08	IN09	IN10
IN07	0	1	1	1	1	0	1	1	1	0
IN01	1	0	1	0	1	1	0	0	1	1
IN02	0	1	1	0	1	1	1	1	1	0
IN03	0	0	1	0	0	1	0	0	0	1
IN04	0	0	1	1	1	1	0	1	0	1
IN05	0	0	1	0	1	1	0	0	0	0
IN06	0	0	1	0	0	1	0	0	0	0
IN08	0	0	1	0	1	1	0	1	0	1
IN09	0	0	1	0	0	1	0	0	1	0
IN10	0	0	0	0	0	1	0	0	0	1
IN02	0	1	1	0	1	1	1	1	1	0
IN03	0	0	1	0	0	1	0	0	0	1
IN04	0	0	1	1	1	1	0	1	0	1
IN05	0	0	1	0	1	1	0	0	0	0
IN08	0	0	1	0	1	1	0	1	0	1
IN09	0	0	1	0	0	1	0	0	1	0
IN07	0	1	1	1	1	1*	1	1	1	1*

Table 9. Transitivity Analysis for IN08

	IN01	IN02	IN03	IN04	IN05	IN06	IN07	IN08	IN09	IN10
IN08	0	0	1	0	1	1	0	1	0	1
IN01	1	0	1	0	1	1	0	0	1	1
IN02	0	1	1	0	1	1	1	1	1	0
IN03	0	0	1	0	0	1	0	0	0	1
IN04	0	0	1	1	1	1	0	1	0	1
IN05	0	0	1	0	1	1	0	0	0	0
IN06	0	0	1	0	0	1	0	0	0	0
IN07	0	1	1	1	1	0	1	1	1	0
IN09	0	0	1	0	0	1	0	0	1	0
IN10	0	0	0	0	0	1	0	0	0	1
IN03	0	0	1	0	0	1	0	0	0	1
IN05	0	0	1	0	1	1	0	0	0	0
IN06	0	0	1	0	0	1	0	0	0	0
IN10	0	0	0	0	0	1	0	0	0	1
IN08	0	0	1	0	1	1	0	1	0	1

Table 10. Transitivity Analysis for IN09

	IN01	IN02	IN03	IN04	IN05	IN06	IN07	IN08	IN09	IN10
IN09	0	0	1	0	0	1	0	0	1	0
IN01	1	0	1	0	1	1	0	0	1	1
IN02	0	1	1	0	1	1	1	1	1	0
IN03	0	0	1	0	0	1	0	0	0	1
IN04	0	0	1	1	1	1	0	1	0	1
IN05	0	0	1	0	1	1	0	0	0	0
IN06	0	0	1	0	0	1	0	0	0	0
IN07	0	1	1	1	1	0	1	1	1	0
IN08	0	0	1	0	1	1	0	1	0	1
IN10	0	0	0	0	0	1	0	0	0	1
IN03	0	0	1	0	0	1	0	0	0	1
IN06	0	0	1	0	0	1	0	0	0	0
IN09	0	0	1	0	0	1	0	0	1	1*

Table 11. Transitivity Analysis for IN10

	IN01	IN02	IN03	IN04	IN05	IN06	IN07	IN08	IN09	IN10
IN10	0	0	0	0	0	1	0	0	0	1
IN01	1	0	1	0	1	1	0	0	1	1
IN02	0	1	1	0	1	1	1	1	1	0
IN03	0	0	1	0	0	1	0	0	0	1
IN04	0	0	1	1	1	1	0	1	0	1
IN05	0	0	1	0	1	1	0	0	0	0
IN06	0	0	1	0	0	1	0	0	0	0
IN07	0	1	1	1	1	0	1	1	1	0
IN08	0	0	1	0	1	1	0	1	0	1
IN09	0	0	1	0	0	1	0	0	1	0
IN06	0	0	1	0	0	1	0	0	0	0
IN10	0	0	1*	0	0	1	0	0	0	1