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An Examination of Resilience in Healthcare Information Systems in the Context of Natural Disasters

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Abstract

Contemporary healthcare information systems (HIS) rely heavily on IT/IS infrastructures to manage primary and essential services. Given that hospitals and HIS have been facing various disruptions from disasters, it is essential to take an integrative approach to help prepare effective coping strategies in disaster situations. To date, little is known about how HIS resilience is achieved. While Information Systems Assurance, IT Capability and Effective HIS use are important, the high degrees of HIS complexity and Interdependence of health information systems also have an impact on resilience. This study integrates a socio-technical perspective and theorizes the effect of disaster experience and influential factors for HIS resilience. HIS resilience will enable healthcare organizations to sustain the continuity of effective performance in terms of critical medical services in a disaster situation.

INTRODUCTION

Healthcare information systems (HIS[1]) play an important role in preventing mistakes and protecting patients from associated safety risks (Smith et al. 2014). Health care organizations are also constantly confronted with stress, shocks, crises and change of environment (Maresso et al. 2013) and this can lead employees to fail to provide good care. Under such situations, resilience of HIS can be important to deal with adversities. Hospital employees rely on resilient systems to continue providing healthcare services during unexpected events (Park et al. 2015). Resilience is important for healthcare systems (Cook 2007) since HIS systems need to convey needed information in the face of changes and challenges. In fact, in an article "Identifying Issues for the Bright ICT Initiative" (Lee and Fedorowicz 2018), the authors identify business continuity and disaster recovery as #5 and #6 of IT leaders' most important/ worrisome concerns. Clearly, resilience is an antidote to such concerns. Yet, the concept of information systems resilience has remained relatively unexplored in the IS literature, and even more so, in the context of healthcare (Smith et al. 2014). Especially, there has been little research regarding whether employees' effective HIS use can contribute to resilient HIS and further, can be achieved through effective HIS use under boundary conditions (HIT complexity and HIT interdependence) in disaster situations. To summarize, the purpose of this study is to: (a) examine the relationship between effective HIS usage, HIS infrastructure and HIS resilience and further (b) investigate the effect of boundary conditions (i.e., HIT complexity and HIT interdependence) on the relationship between effective HIS use and HIS resilience by comparing HIS in two situations – hospitals that have been through disaster experience vs those that have not.

[1] We refer to Health Information Systems (HIS) and Health Information Technology (HIT) interchangeably to avoid monotony.

THEORY

In this section, we develop hypotheses with key constructs of this paper. The hypotheses posited in this section are summarized in Figure 1.

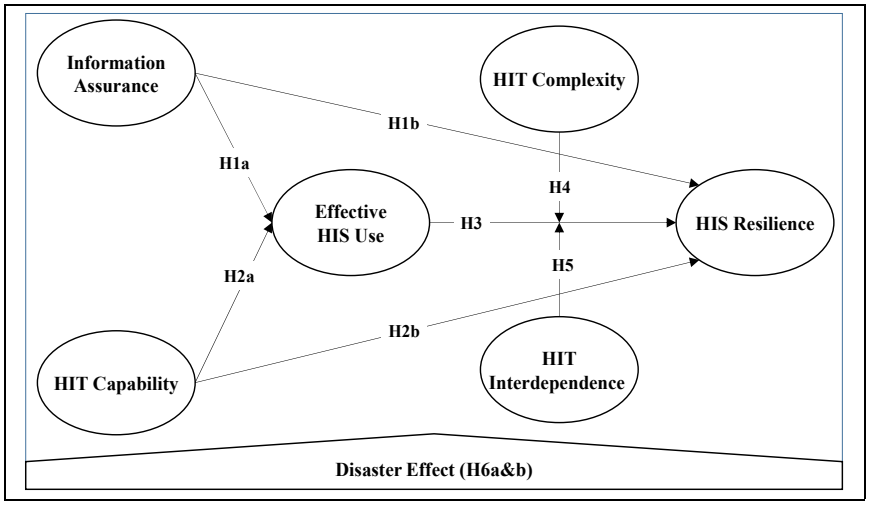

Figure 1. Research Model

Perceived information Systems Resilience

Employee's perceptions of health *information system resilience* is defined as the belief that the HIS is characterized by the ability to bounce back from negative experiences and by flexible adaptation to certain contexts. This definition is based on individuals' belief regarding the capacity of their organization's information systems to maintain and renew themselves, particularly in the presence of stressors, or to absorb or cushion themselves against damage or loss (Rose 2004). Resilience has been widely recognized as a factor that effectively preserves operational continuity and delivery of care by motivating employees to perform better, increasing employee job satisfaction and commitment, and improving group and organizational effectiveness (See Avey et al. 2010; Luthans et al. 2007; Peterson et al. 2011). *Resilient* systems have the ability to "maintain positive adjustment under challenging conditions" (Sutcliffe and

Vogus 2003, p. 95). Therefore, resilience addresses the continuity of health services to ensure the provision of healthcare without interruptions, as disruptive natural hazards could cause (Mohleji 2014). *HIS resilience* reflects the availability of information systems that focus on enhancing the hospital's competence in restoring efficiency by increasing the ability to process feedback quickly (Sutcliffe and Vogus 2003). Thus, resilient systems, when supported by a flexible infrastructure, can help businesses maintain their operational capabilities as they adapt and respond to challenges posed by various disruptions and threats related to security and privacy[2]. The concept of HIS resilience is associated with reduced failure probability, reduced consequences from failure, and reduced time to recover as experienced by individuals, according to Bruneau et al. (2003).

The Effect of Information Assurance

Ezingeard et al. (2007) describe *information assurance (IA)* as the certainty that within an organization, information assets are reliable, secure, private, accurate, and available. They suggest that IA typically defines how these assets (i.e., data and information within both the tangible and the virtual bounds of the organization) should be secured to provide maximum benefit. This involves protecting and defending both information and IS, by ensuring their availability, integrity, confidentiality, identification and authentication, and non-repudiation (Barker 2003). Therefore, The perceptions of IA — surrounding the guarantee that the security system will behave as expected—would lead employees to use their systems more effectively. Sharing or using sensitive patient information in a large, distributed, and heterogeneous hospital could lead to security and privacy vulnerabilities (Braghin et al. 2008), which is to say that the

[2] http://www-935.ibm.com/services/us/bcrs/html/resilience.html

information might be compromised or threatened by attackers, or inadvertently exposed by HIS users. Thus, employees with positive IA experiences are likely to accumulate experience of successful use of HIS. Therefore, if employees believe that their information systems are resilient enough to handle unexpected events, they will continue using their information systems without concerns about data/information disruptions, and eventually their belief will encourage them and enhance their work performance.

H1a*: IA will positively affect effective IS use.*

Since IA is seen as a meta-capability that is developed through the interaction of the various features of information systems, in hospitals employees would tend to believe their HIS to be more resilient when they have higher levels of IA. HIS should be able to provide substantive protection in using hospital information to achieve high levels of security and privacy. It would be correct to suggest that a hospital could institute effective use of their IS and expect high systems resilience and it is the IA that effects system resilience. Therefore, individuals who recognize that their hospital's systems are protected would also tend to believe that their health information system has positive resilience.

H1b: *IA will positively impact information systems resilience.*

The Effects of HIT capability on Systems Resilience

HIT capability is important to hospitals that deal with critical uncertainty on a regular basis as well as to individuals for whom crisis is an unfamiliar, yet potentially very real circumstance (Barton 2006). A core of IS capability is the ability to facilitate the exploitation of IT, measurable in terms of IT activities supported, and resulting in improved business performance. In this study, we consider HIT capability as the ability of a hospital to configure, implement,

apply, and evaluate the existing and emerging information in order to construct an integrated and reliable HIS infrastructure (Weill and Vitale 2002).

Hospital employees are involved with many types of health information systems and it is important for them to use effectively for patient care in the field. They, as HIS users must possess the related healthcare knowledge to deal with patients. Thus, employees' skills and knowledge of hospitals and their information systems are important for effective use in critical IT activities. Health IT capability allows users to configure, implement, apply, and evaluate IT so that let they can use HIS more effectively. Employees are better able to use their HIS with greater HIT capability. They are more likely to be able to integrate HIS functions with hospital processes. We argue that users who know about the IT capability and have positive perceptions of such capability will achieve a higher level of effectiveness in using HIS.

H2a: *HIT capability will positively affect effective HIS use.*

An effective HIT capability is critical in organizing and efficiently managing health applications. Moreover, external IT linkages help hospitals to exchange information and communicate with partners in a timely manner. As Melville et al. (2004) has suggested, HIT capability helps to shorten the time for responding to change, processing information, and implementing strategies because the capability permeates and infuses ordinary hospital activities and processes. This implies that a strong HIT capability help to build an efficient communication and information exchange environment within and across hospital boundaries, thereby improving responsiveness, as business organizations do (Shang and Seddon 2002). Therefore, given the increasing embeddedness of HIT applications in hospital organizational processes, the extent to which a hospital can rapidly respond and recover is likely to be heavily dependent upon HIT capability and this will be reflected in employee perceptions.

***H2b**: HIT capability will have a positive impact on HIS resilience.*

Effective information systems use

Burton-Jones and Grange (2013) have suggested the 'effective IS use' concept. Orlikowski (2000, p. 425) notes, "technology *per se* can't increase or decrease the productivity of workers' performance, only the use of it can." Based on a review of IS use literature, we define *effective IS use* as "*using a system in a way that helps attain the goals for using the system.*" The concept, 'effective IS use', focuses on consequences of IS use (i.e., successful/unsuccessful or effective/ineffective). It indicates the effectiveness of use to the extent that it helps carry out the task (Burton-Jones and Straub 2006). In fact, given the complexity of modern IS such as ERP, having to learn to use the new technology itself can be frustrating (Boudreau and Robey 2005). For example, according to Morris et al. (2010), ERP system users perceive ERP systems as stripping out the significance and variety of an employee's work that was inherent in their job. In other words, employees feel that their jobs are somehow less important because some tasks or even entire jobs are subsumed by IS to a large degree. However, when they are familiar with the system and know how to effectively use it to leverage their job, this would be positively affect their usage of IS.

In terms of HIS resilience, since *effective IS use* is based on the willingness to repeatedly use existing systems, employees will believe that HIS resilience increases because the confidence regarding IS resulting from effective use of systems will be helpful and eliminate the feeling that the systems are not a substitute for their actual work or subsume their jobs. Therefore, we predict that *effective IS use* will positively influence employees' perception of HIS resilience.

***H3*: *Effective IS use is positively associated with HIS resilience*.**

Moderating effect of HIT complexity

In a complex IT environment, an organization needs to address important organizational issues such as simplifying operational processes by applying complex and sophisticated knowledge regarding sub systems, and coping with varied external stakeholders (Wade and Hulland 2004). In this study, we argue that under complex conditions, effective HIS use would result in high resilience. Hospital employees who use their HIS effectively are likely to accept challenges, since their usage could be embedded in their cognitions which impact their task performance (Alavi and Leidner 2001). Attewell (1992) suggested that technically complex IS require end-users to work with unfamiliar technologies and often require them to perform their tasks in different ways. Employees deal with this complexity by accumulating knowledge regarding effective HIS usage because technical complexity affects both the application and business context knowledge that employees need to acquire to effectively use those IS innovations (Kang and Santhanam 2003). Thus, employees as effective users of HIS are often the primary source for such knowledge and effective IS use can be a critical factor through which end users acquire such knowledge. In contrast, for low complexity, achieving knowledge on IT is specific to what users have to deal with. As a result, in a complex environment, employees using IS effectively are better able to deal with adversaries, incidents, and disasters in a coordinated and effective manner, and are thus more likely to achieve HIS resilience.

***H4**: HIT complexity will positively moderate the impact of HIT capability on business process agility such that, for the same level of effective IS use, the HIS resilience will be higher for users who perceive high HIT complexity than those of users who perceive low HIT complexity.*

Moderating effect of HIT interdependency

Interdependence refers to the degree to which the actions and outcomes of one unit are controlled by or contingent upon the actions of another unit. If interdependence is high then the time, cost,

and effort necessary to coordinate the process will be high (Albino et al. 2002). Thus, when actions taken by one referent system affect the actions or outcomes of another referent system (McCann and Ferry 1979). Interestingly, past studies have shown *negative* results that as interdependence increases, the enterprise must spend more time and effort on work (Giachetti 2006). IS applications which support interdependent tasks face implementation difficulties due to the misfit between the routines embedded in existing interindividual cognitions and those required for effective performance with new technologies (Edmondson et al. 2001). According to Robey et al. (2002), the implementation of interdependent-use IS innovations is frequently brought by new business processes that disrupt existing task routines. Such changes require IS users to develop new routines to cope with IS interdependencies (Edmondson et al. 2001). That is, when HIS interdependence is high, effective IS use has a weak effect on HIS resilience.

H5*: HIT interdependence will moderate the relationship between effective IS use and HIS resilience such that, for the same level of effective IS use, the HIS resilience will be lower for users who perceive high HIT interdependence than those of users who perceive low HIT interdependence.*

Disaster Effect

People construct their own reality and evaluate risks according to their subjective perceptions. Prior studies show that past experience with disasters is an important factor in influencing people's perceptions of hazards (See, Jackson 1981). That is, disaster experiences can change their perspectives on IT related factors. This leads to different effects of HIT complexity on the relationship between effective IS use and IS resilience in contrast to before a disaster experience. Under disaster situations, employees would have experienced IT as more complex to deal with, because disaster situations can reduce access to information (Amaratunga et al. 2009), increase difficulties for communication and collaboration (Lizarralde and Massyn 2008), increase pressure to act quickly, and place responders at risk (Kathleen Geale 2012), individuals' limited

rationality may be maximized. This can make hospital employees feel their complex IT would be less effective in the relationship between effective IS use and IS resilience, since employees act within high levels of uncertainty which any complex IT would prevent them from performing their work, which can potentially have far-reaching effects.

H6a: *The effect of HIT complexity on relationship between perceived effective IS use and HIS resilience will be weaker in employees with disaster experience than those with no disaster experience.*

Disasters could cause employees to become relatively more concerned that their information systems will not properly function and prevent them from completing the tasks. This would impede hospital employees and have an impact on their perceptions of HIS resilience. That is, given that such disaster happened in the context of hospitals, employees reporting more experiences may view interdependence as helpful in using HIS. It would suggest that the effect of interdependence on the relationship between effective IS use and HIS resilience may be further strengthened by disaster experiences.

H6b: *The effect of HIT interdependence on relationship between effective IS use and HIS resilience will be stronger in employees with disaster experience than ones with no disaster experience.*

RESEARCH METHOD

Research Setting and Data Collection

To conduct this study, hospitals in USA that had been previously affected by a critical incident (natural disaster) were selected as sites from which to collect survey data. A survey was conducted in June 2017 at these hospitals in USA. Participants were randomly selected by a survey company. They are hospital employees including physicians, nurses, HIT support personnel, and administrators. After distribution of a total of 450 surveys, 306 questionnaires were considered usable, which gave an effective response rate of 55.6%.

Measures

To develop the survey instrument, generally accepted instrument development guidelines were followed. Many items were derived from earlier work. The domain of the relevant construct was initially specified, and the items were subsequently developed based on the conceptual definition. The preliminary instrument was pilot tested for clarity.

Table 1. Constructs

Variables	# of items and scale (*references*)
Information assurance	Eight items were used with seven-point Likert scale. (Torkzadeh and Dhillon 2002)
HIT capability	Seven items were used with seven-point Likert scale. (Weill and Vitale 2002)
HIT Interdependence	Eight items were used with seven-point Likert scale. (Sharma and Yetton 2007)
HIT complexity	Seven items were used with seven-point Likert scale. (Lard 2014) (Xia and Lee 2005)
Effective HIS use	Eight items were used with seven-point Likert scale [Kettinger et al.(2013)]
Perceived IS resilience	Twelve items were used with seven-point Likert scale. (Park et al. 2015)
Control Variables	Job experience, Tenure, Job title, Gender, Education, Age, IS type, Overall job experience

ANALYSIS AND RESULTS.

The hypotheses were tested using structural equation modeling (SEM) procedures with AMOS 4.0. Using SEM allows for a simultaneous evaluation of both the quality of measurement (the measurement model) and the construction of interrelationships (the structural model).

Measurement Model Estimation

Table 2 exhibits the means, standard deviations, zero-order correlations, and reliability estimates. As seen in Table 2, the AVE of the diagonal elements in the matrix indicates that the AVE of each construct was greater than its correlations with other constructs. The composite scale reliability for each construct, which is similar to Cronbach's alpha, was higher than 0.80 (i.e., higher than the recommended cut-off of 0.70). The factor loadings of indicators associated with

each construct were high (greater than 0.70), indicating adequate reliability (Factor loadings are up on request).

Table 2. Inter-construct Correlations (N=306)

Construct	1	2	3	4	5	6
1. HIS Resilience	**0.765**					
2. Effective HIS Use	0.806	**0.808**				
3. HIT Complexity	0.649	0.510	**0.788**			
4. Information Assurance	0.446	0.303	0.373	**0.772**		
5. HIT Interdependency	0.256	0.181	0.461	0.21	**0.749**	
6. HIT Capability	0.482	0.338	0.609	0.608	0.416	**0.795**
AVE	0.585	0.653	0.620	0.597	0.561	0.632
Cronbach's alpha	0.941	0.923	0.897	0.903	0.889	0.903
Composite Reliability	0.948	0.937	0.919	0.922	0.911	0.923
Note: The boldface numbers on the diagonal are the square root of the variance shared between the constructs and their measures.						

Testing the Structural Model

The PLS path coefficients for testing the structural model are shown in Figure 2. First, the effect of IA on Effective HIS use ($\beta = 0.350$, $p<0.001$) and HIS resilience ($\beta = 0.108$, $p<0.05$) are statistically significant. Next, the effect of HIT capability on Effective HIS use ($\beta = 0.303$, $p<0.001$) and HIS resilience ($\beta = 0.166$, $p<0.01$) were both significant. Third the effect of HIS use on HIS resilience was significant ($\beta = 0.591$, $p<0.001$). As shown in Figure 2[3], HIT complexity *positively* moderates the effect of Effective HIS use on HIS resilience ($\beta = 0.33$, $p < 0.001$) when employees do not have disaster experience, while there is no moderating effect for disaster experienced employees.

[3] Direct effects of IT complexity and IT interdependence on HIS resilience are -0.044(0.255***) and 0.304***(-0.116) respectively.

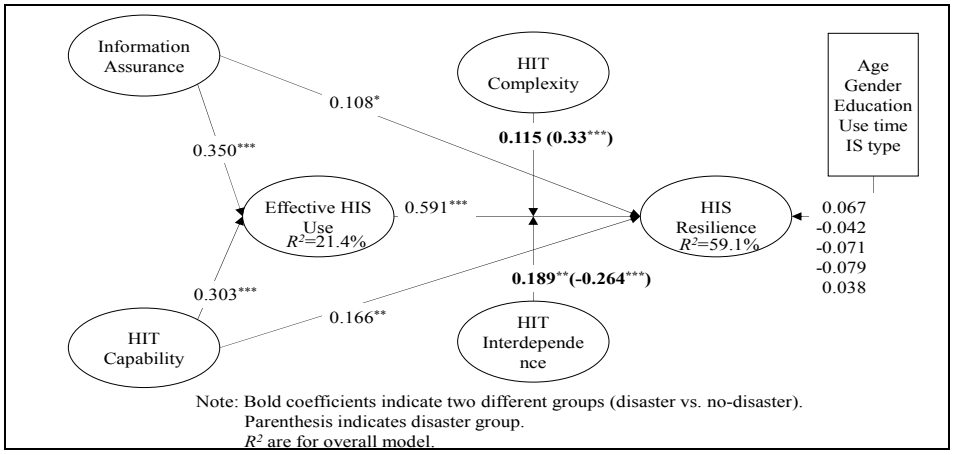

Figure 2. Results of Data Analysis

Unexpectedly, at high levels of HIT complexity (H4), effective HIS use does not increase HIS resilience in disaster situation. On the other hand, HIT interdependency (H5) *negatively* moderates the relationship between effective HIS use and HIS resilience for no-disaster experience employees (β = -0.264, p < 0.001), but *positive* effect on the relationship (β = 0.189, p < 0.001) for disaster experience employees which partially supported H5.

For Hypothesis 6a, the effect of HIT complexity on the relationship between effective IS use and HIS resilience showed a significant difference between two groups (T-value = -2.514). For hypothesis 6b, the effect of HIT interdependence on the relationship also showed a significant different result (T-value = 5.711). Thus, both hypotheses H6a&b were supported.

Table 3. Differences in the effect of disaster experience[4]

Hy	Path	Disaster		No-Disaster		Comparison	
		Path^	S.E.	Path	S.E.	$P. Diff.	T-Value*
H6a	HIT complexity	0.115	0.006	0.330	0.006	0.215	-2.514*
H6b	HIT interdependence	0.189	0.007	-0.289	0.005	0.453	5.711***

$P.diff.: Difference between virtual and on-site path coefficients.
*$p < 0.05$, **$p < 0.01$

DISCUSSION

[4] We performed a multi-group comparison *T*-test.

Based on the results, this study makes a theoretical contribution to the IS and healthcare HIT literature by exploring a consideration that has not been investigated to this point. Namely, it demonstrates the importance of including contextual measures such as information systems resilience within the model, as these measures are important notions in hospital context like those experienced in hospital organizations. Second, this paper contributes to bridging the gap between resilience of health information systems and IS success factors by incorporating information use concept. In the health care area, successful management of HIS infrastructure is crucial for health practices. Third, the framework developed in this paper classifies resiliencies and helps to predict and explain factors affecting HIS resilience through users' perceptual factors. In the present study, we introduced and reasoned about the influence of HIT infrastructural factors on the relationship among employees' usage of HIS and HIS resilience in hospital environments. Finally, our study provides insights into the different paths through which resiliencies are worthy of more research attention under the hospital context. In abnormal context such as disaster, uncertain situation, the effect of resilience could give different aspects individuals' IT utilization and performance.

Practically, hospitals routinely encourage their employees to believe that their organization is highly resilient so as to minimize negative perceptions of organizational risks and to improve the organization's performance through resilience. Hospitals can develop programs to improve resilience by implementing training on how to manage difficult situations and by creating positive beliefs about their information systems. HIS resilience not only helps motivate hospital employees to keep doing their work under stressful conditions such as disasters, but also leads them to overcome the psychological barriers that they encounter while working. In addition, demonstrating that the hospital's systems would function under adverse conditions——would

also serve as a positive reinforcement of the hospital's IS resilience for the system users. In a hospital setting, it is important to train employees to deal with unexpected conditions based on preplans that are in place in all U.S. hospitals (Federal Emergency Management Agency 2010). The findings of this study suggest that employees' perception of resiliencies are important not only for maintaining satisfaction with the organization's IS/IT and system resilience, but also for facilitating employees' job related to HIS.

CONCLUSION

In conclusion, the research described in this paper was intended to further our understanding of HIT complexity and interdependency under healthcare circumstances which are constantly facing unexpected events to both employees and organizations. To date, there has been little research on them in terms of hospital IS improvement in this disaster context. Our study reveals complexity and interdependency play roles in improving HIS resilience differently under disaster situations from normal situations.

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(Further references are up on request)