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CONTRIBUTIONS OF SOCIAL NETWORK ANALYSIS FOR THE MODELING OF ORGANIZATIONAL RESILIENCE IN HEALTH SERVICES

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My ADHD makes it hard for me to focus
and focus sounds like hocus pocus and I really
like to magic a whole whole a lot. Abracadabra.
(Author unknown)

ABSTRACT

In order to survive, socio-technical systems display resilient performance (RP) to cope with variabilities. RP is emergent, arising from interwoven networks that involve several types of interactions between people, technologies, and work organizations. This thesis explores the role of the networks of social interactions in RP, in the realm of health services. In particular, the thesis addresses the problem of how to measure the contribution of individual actors to RP, considering their centrality in social networks as a proxy of that contribution. Although previous studies pointed out the role of social interactions in the rise of RP, they did not provide tools nor a corresponding theoretical framework for the assessment of organizational resilience based on social interactions. In order to address this gap, the present thesis is structured into three articles. The first article proposes an approach for the identification of key players that support RP, based on a composite resilience score (RS) for each actor comprised of the three most common metrics used in network analysis at the individual level, namely in-degree, closeness, and betweenness, in addition to two non-network attributes of actors - availability and reliability. The RS might be calculated for each actor, in four networks related to the four abilities of resilient systems, namely monitor, anticipate, respond, and learn. A global RS for each might also be calculated, as the total of the RSs from the ability-based networks. The second article presents an approach to developing and interpreting multilayer networks in light of resilience engineering. Layers correspond to the four abilities of resilient systems. Two multilayer networks were developed: one considering that actors are 100% available and reliable (work-as-imagined) and another considering suboptimal availability and reliability (work-as-done). The multilayer networks were analyzed through actor-centered (Katz centrality, degree deviation, and neighborhood centrality) and layer-centered metrics (inter-layer correlation, and assortativity correlation). Data for both papers 1 and 2 were gathered from the same 34-bed intensive care unit of a large teaching hospital in Southern Brazil. Finally, the third paper presents an approach for assessing the match between task risk and actors' contribution to resilient performance, measured by the RS developed in the first paper. The law of requisite variety (LRV), which states that a complex controller (i.e., actors who have a high RS) is necessary for coping with a complex process (i.e., high-risk tasks), is the theoretical lens for analyzing that match. Cluster analysis divided the actors into first-order and second-order resilience groups, even though the clusters did not differ regarding the task risk. Based on the LRV and considering that the performance of the ICU is more often than not successful, the findings suggest that even the actors at the second-order resilience cluster reached a minimum threshold of effective social interactions. Data for the third paper was gathered from a six bed-cardiac intensive care unit located at the same hospital where data was gathered for the previous two papers.

Keywords: Resilience Engineering. Network Theory. Healthcare Systems, complexity, intensive care unit.

SUMÁRIO

1 INTRODUCTION

1.1 CONTEXT

Health services (HSs) aim at providing safe and effective care in complex organizations strapped by heavy patient loads, limited staffing, and shrinking financial resources (IRVINE *et al.*, 2018). Thus, the provision of care involves putting together many resources to fulfill an array of different service requirements (WHO, 2000).

In order to cope with this complexity, HSs need to continuously adapt their performance through dynamic interactions between a variety of professionals (doctors, nurses, nursing technicians, physiotherapists, speech therapists, among others), stakeholders (family members and patients), technologies, and managerial artifacts (CARAYON *et al.*, 2011; BRAITHWAITE *et al.*, 2018). Due to these interactions, which can be influenced but not fully controlled, HSs are widely characterized as complex socio-technical systems (CSTS) (BRAITHWAITE, 2018). The delivery of healthcare is dependent on effective communication. In fact, one of the patient safety goals of the Joint Commission on Accreditation of Healthcare Organizations is to improve communication among healthcare professionals (HCPs) (VERMEIR *et al.*, 2015; JCMAHO, 2007).

Although, communication is a broader concept, social interaction involves the careful assessment of the practices of everyday communicating between people in various (usually) real-life contexts, such as doctor-patient, and human-computer communication. Healthcare systems are inherently task-oriented, and communication between healthcare providers is essential for effective performance; since communication is necessary, healthcare systems require reliable communication channels to collect and disseminate information. If such channels fail, essential tasks may be delayed, omitted, or carried out in an otherwise counterproductive manner (Fitzhugha and Butts., 2021). However, healthcare systems exposed to disruptive environments require communication systems that are either robust enough to withstand exogenous shocks or resilient enough to restructure and adapt to disruption, in this terms, Pow et al. (2012) cite the utility of social network analysis (SNA) for investigating communication in hospital context so that interventions may be identified (or strategies defined to increase the likelihood that staff will adopt interventions) to improve communication on a patient care unit.

However, communication failure among HCPs is one of the most frequently cited causes of preventable harm to patients (Schallmo et al., 2019). For example, a retrospective review of 16,000 in-hospital deaths found that communication errors contributed to adverse outcomes almost twice as frequently as inadequate clinical care (Gurses; Xiao, 2006). Communication failure was reported as one of the major causes of adverse patient outcomes by Khajouei et al. (2018). Ineffective communication was also found to negatively affect HCPs satisfaction (Tiwary et al., 2019) and efficiency in care delivery (Schallmo et al., 2019). Ineffective communication can play out in important clinical interactions such as (i) handover of responsibility for patient care and of information relating to patients from one HCP to another (Sujan et al., 2015); and (ii) multidisciplinary rounds, in which a set of clinicians meet at the bedside, discuss the patient condition, and design the plan of care (Cardarelli et al., 2009).

Furthermore, several authors emphasize that communication is critical to a system's resilience (Jain et al., 2018; Pawar et al., 2020). From an organizational perspective, resilience is the intrinsic ability of a system to adjust its functioning prior to or following changes and disturbances to sustain operations even after a major mishap or in the presence of continuous stress. This definition also includes the ability to exploit opportunities that arise, rather than simply survive threats (Hollnagel, 2015).

In order to be resilient, a HS must have the following four abilities: (i) to respond to regular and irregular threats in a robust yet flexible manner, (ii) to monitor what is going on, including its own performance, (iii) to anticipate risks (risk events) and opportunities and (iv) to learn from experience (Hollnagel, 2017). Designing a system through the lens of organizational resilience implies promoting the development of resilience at different (and between) levels of the system, whether individual, team, or organizational (NEMETH et al., 2009; HOLLANGEL et al., 2006). Communication can play an important role in the deployment of these four abilities.

1.2 RESEARCH PROBLEM

Although communication[1] between caregivers is important to resilient performance, studies on that relationship are still scarce. Anderson *et al.* (2020) argue that resilient healthcare research

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[1] Hereafter, the terms communication and social interactions are used indistinctly.

and practice should account for the prominence of social, cultural and organizational factors in healthcare work. This further justifies the interest of this thesis in social interactions. Some of the previous studies are solely based on qualitative data. For example, Wachs *et al.* (2016) found that collaborative work between caregivers in emergency departments was a frequent manifestation of resilient performance. Similarly and Alders (2019) concluded that social interactions facilitated adaptations carried out by nurses in an acute care unit. These adaptations were thought to be most effective at responding and least effective at monitoring.

In turn, other studies have explored the link between communication and resilience based on quantitative data. These studies are usually based on applications of social network analysis (SNA) for the modelling of social interactions. SNA is a method for analyzing social interactions among individuals and organizations, mapping patterns of relationships and information flows (e.g., DE BRÚN; McAULIFFE, 2018). In SNA, individual actors are nodes, and their social interactions are links in a network (WASSERMAN; FAUST, 1994).

Wehbe *et al.* (2016) used SNA in a study of construction sites. They found that social networks with more interactions have higher resilience and better safety performance. In healthcare, while there are several studies based on SNA, very few explicitly address resilience. For instance, Braithwaite *et al.* (2017) re-interpreted social networks developed by Creswick *et al.* (2009) in an emergency department, from a resilience perspective. The finding that individuals were much more closely connected to colleagues within their professional groups than across them was argued to be detrimental to resilience. Salwei *et al.* (2019) used SNA for assessing adaptation of clinical teams to different levels of complexity in critical care. They found two adaptation mechanisms when complexity grows: increase in the number of people, team activities, and interactions within the team; and increase in two-way communication between team members.

Despite the contributions of these earlier studies, there are still many knowledge gaps on the relationships between resilience and social interactions. This thesis explores three of these gaps in the context of healthcare. The first research gap arises from the fact that not all actors have the same relevance in a social network (PAGE, 2010; BORGATTI, 2006). As a consequence of that aspect, it is reasonable to expect that different individuals influence the system's resilient performance in different ways and intensities. In SNA, the identification of the actors' relevance has been framed as a problem of finding the most central individuals, or key players. These individuals are those "optimally positioned to quickly diffuse information, attitudes, behaviors or goods and/or to quickly receive the same" (BORGATTI, 2006, p. 22). The optimal selection of key players depends on what they are needed for (BORGATTI, 2006). Although the notion of key players for resilient performance makes sense in theory, there is no available method for operationalizing this idea into practice.

The second research gap is related to the view of resilience as layered interwoven networks that adapt to surprises as conditions evolve (WOODS, 2015). While sound in principle, such perspective of resilience has remained mostly at a conceptual level (BERG *et al.*, 2018). One of the reasons for that lack of operationalization is the lack of clarity of previous studies on the relevant interwoven networks. This thesis explores that gap by assuming that social interactions associated with Hollnagel´s (2017) four resilience abilities might be interpreted as relevant interwoven networks that give rise to resilience. As social interactions take place in messy real-life situations, it is reasonable to expect that an interaction may simultaneously target at two or more abilities. Also, interactions focused on a certain ability (e.g., monitor) may trigger other ability-centered interactions (e.g., respond) at a later moment in time. However, while dependence between resilience abilities is expected in theory (PATRIARCA, *et al.*, 2018a), empirical data supporting the understanding of what that looks like in practice is scarce. In particular, this thesis investigates the emergent network that arises from flattening the four ability-based networks (i.e., monitor, respond, anticipate, learn). This emergent network is referred to in literature as a multilayer network (NICOSIA *et al.*, 2013). Each layer consists of nodes (i.e., people) and edges (i.e., purpose of the interaction). Although sharing the same nodes, each layer conveys different information on the edges. If the same actors are present in every layer the network is denoted as multiplex (NICOSIA *et al.*, 2013), which is the type investigated in this study. The multilayer network is effectively a new network, and therefore it offers insights that are not observable at the single-layer level – e.g., it makes clear, in a concise way, the extent to which actors interact with the same people regardless of the purpose of the social interaction (DICKINSON *et al.*, 2016).

The third research gap refers to the lack of methods for assessing whether the social interactions that contribute to resilient performance match the risks of the tasks carried out by actors. These social interactions might be interpreted as part of the mechanisms of control in socio-technical systems, and therefore they should match the nature of the controlled process. The thesis addresses this assumption in light of the law of requisite variety (LRV), which posits that the variety (possible states) of the regulated (output) variable can be reduced to an acceptable level only by the sufficient variety of the regulating variable (ASHBY, 1956; 1958). The law is also conveyed as “only variety can destroy variety” (ASHBY, 1956, p. 207) and as “every good regulator of a system must be a model of that system” (CONANT; ASHBY, 1970). Despite being decades old, the LRV remains mostly a metaphor, without practical operationalization in the human factors field. This reflects a broader drawback in human factors, which has found it challenging to translate complexity theory into methods that can be used by practitioners and researchers (WALKER *et al.*, 2010).

When addressing the three gaps aforementioned, this thesis will use a mix of qualitative and quantitative data. This mix is a strength in relation to several other studies of SNA, which have been criticized for taking only a quantitative perspective (EMIRBAYER; GOODWIN, 1994; KNOX *et al.*, 2006). Thus, a mixed-methods approach is expected to provide a comprehensive view of the relationship between resilience and social interactions.

1.3 RESEARCH QUESTIONS

Based on the context and research problem, the main research question to be investigated in this thesis is stated as follows*: How can social network analysis be used for the modelling of organizational resilience in healthcare services?*

That main question is broken down into three secondary questions, as follows:

a) How to identify key players in social networks from a social network analysis perspective?
b) How can a multilayer social network be developed to map resilience in a socio-technical system?
c) How can the match of task risk and actor’s contribution to resilient performance be assessed?

1.4 OBJECTIVES

This thesis's main objective is to develop means for the use of social network analysis for the modelling of organizational resilience, in the context of healthcare services.

As for the secondary objectives, they are as follows:

a) to propose an approach for the identification of key players in social networks related to the four abilities of resilient systems;
b) to propose an approach for the development and interpretation of multilayer social networks in light of resilience engineering; and
c) to propose an approach for assessing the match between task risk and actors´ contribution to resilient performance.

1.5 RESEARCH STRATEGY

Design Science Research (DSR) is the research strategy used in this thesis. DSR aims at the development of artifacts (solutions) to solve ill-structured problems that have theoretical and practical relevance (HOLMSTRÖM *et al.*, 2009).

DSR provides scientific contributions of a prescriptive nature, which means an emphasis on answering "how" questions instead of "what" questions. However, DSR usually includes a descriptive phase for a deep understanding of the problem (HOLMSTRÖM *et al.*, 2009). The problem addressed in this research is concerned with how to model organizational resilience based on SNA. As previously mentioned, that problem has practical relevance since both resilience and social interactions are necessary for the effective performance of health services.

According to March and Smith (1995) DSR usually produces one or more of the following four types of artifacts: (a) *constructs*: constitute a conceptualization used to describe problems within a domain and to specify their solutions; (b) *models*: set of propositions or statements expressing relationships between the constructs; (c) *methods*: set of steps for performing a task; and (d) *implementations* or instantiations, corresponding to the operationalization of constructs, models and methods. Vaishnavi and Kuechler (2007) include a fifth artifact: better theories (or theory development), either in terms of contributions related to the method of constructing an artifact or in terms of analyzing the relationship between its elements.

In the present research study, the main proposed artefacts are the operationalization approaches mentioned in the secondary objectives, which can be interpreted as methods for the modelling of organizational resilience. These approaches, when jointly considered, answer the main research question. The test of the proposed approaches in real-world healthcare services correspond to the instantiations mentioned by March and Smith (1995).

This research is outlined in three stages, which correspond to chapters 2, 3, and 4, of this thesis. Table 1 shows the contribution of each chapter to achieve the objectives of the thesis.

Table 1 - Structure of this thesis

	Research question	Main Goal	Data Collection Period
Paper 1 (chapter 2)	RQ1: How can key players that contribute to resilient performance in social networks be identified?	To develop an indicator to assess the contribution of individual actors to systems´ resilient performance	November 2019 to February 2020
Paper 2 (chapter 3)	RQ1: How can a multilayer social network be developed to map resilience in a sociotechnical system? RQ2: How can traditional metrics used in multilayer social networks, at both actor and layer levels, be interpreted in light of resilience engineering?	To develop an approach for the development and interpretation of multilayer social networks in light of resilience engineering	November 2019 to February 2020
Paper 3 (chapter 4)	RQ1: how can the match of task risk and actor's contribution to resilient performance be assessed?	To develop an approach for assessing the match between task risk and actors' contribution to resilient performance	June 2021 to August 2020
Conclusion (chapter 5)	RQ1: How can social network analysis be used for the modelling of organizational resilience in healthcare services?	The approaches developed in the three papers are revisited, emphasizing how the answered the main research question	

First paper - Identifying key players in social networks: a resilience engineering perspective - the objective was to assess who are the most central actors in each network (monitor, anticipate, respond and learn), creating the resilience score of individuals, to identify the main actors based on each of the four resilience potentials and their availability and reliability. A global resilience score was also developed based on the same scores to identify the main actors, considering the four networks. For this, a survey was carried out in an intensive care unit, a sociotechnical system.

The second paper - Monitor, anticipate, respond, and learn: developing and interpreting a multilayer social network of resilience abilities – the study presents an approach to develop and interpret multilayer networks in light of resilience engineering. Layers correspond to the four capabilities of resilient systems: monitor, anticipate, respond, and learn. The proposal is applied in a 34-bed intensive care unit. A questionnaire was devised and answered by 133 staff members to map relationships between actors in each layer, including doctors, nurses, nurse technicians, and allied health professionals. Two multilayer networks were developed: one considering that actors are 100% available and reliable (work-as-imagined) and another considering suboptimal availability and reliability (work-as-done). The multilayer networks were analyzed through actor-centered (Katz centrality, degree deviation, and neighborhood centrality) and layer-centered metrics (inter-layer correlation and assortativity correlation). Strengths and weaknesses of social interactions at the ICU are discussed based on the adopted metrics.

The third paper – Law of requisite variety in practice: assessing the match between task risk and actors' contribution to resilient performance. This study addresses the gap that the variety of the regulated process should match the variety of the controller by introducing an approach for assessing the match between task risk (i.e., regulated process) and actors' contribution to resilient performance (i.e., controller). The proposed approach was applied to an intensive care unit (ICU), in which staff members answered the survey questionnaire that gave rise to the risk and resilience scores. Cluster analysis grouped the respondents into two groups named first-order and second-order resilience actors, even though the clusters did not differ regarding the risk score. Based on the LRV and considering that the performance of the ICU is more often than not successful, these findings suggest that even the actors at the second-order resilience cluster reach a minimum threshold of effective social interactions.

1.6 DELIMITATIONS

The scope of this doctoral thesis has some delimitations, as follows:

a) it is focused on ICUs. Also, only interactions between HCPs that work in the ICU were considered. This work did not account for interactions with professionals from other hospital´s units;

b) it is cross-sectional, rather than taking a longitudinal perspective of how social networks evolve over time;

c) it approaches the resilience concept in light of resilience engineering, which takes a socio-technical perspective of resilience. Thus, the perspective of individual and psychological resilience, which is commonly adopted in the healthcare literature (TUGADE; FREDRICKSON, 2004; BOZDAĞ; ERGÜN, 2020) is not emphasized; and

d) the investigation in the studied healthcare services gave rise to practical recommendations for the improvement of the work system design. However, the uptake of these recommendations by the studied services was not assessed.

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5 CONCLUSIONS

5.1 THESIS MAIN OBJECTIVES AND CONTRIBUTIONS

This thesis had the general objective of proposing a model for integration between resilience engineering and social interaction, emphasizing intensive care units. As for the specific objectives, three were established: (i) To propose an approach for the identification of key players in social networks related to the four abilities of resilient systems; (ii) To propose an approach for the development and interpretation of multilayer social networks in light of resilience engineering; and (iii) To propose an approach for assessing the match between task risk and actors´ contribution to resilient performance.

The second chapter of this thesis contemplates the specific objective (i), through a social network survey was proposed a method to identify relevant key players based on the modeling of interactions associated with the four abilities of resilient systems: monitor, anticipate, respond, and learn. Social interactions were captured for each ability, and a resilience score were proposed for each player, combining three network metrics named as in-degree, closeness, and betweenness, two non-network metrics named as availability and reliability, which were assessed through Likert-style questions. As a result, the social network applied focused on the identification and ranking of relevant players, in light of resilience engineering. There are several opportunities to improve this manuscript such as: (i) investigation of the influence of other contextual factors for being a key player in light of RE (e.g., use of electronic devices); (ii) gather longitudinal data, evaluating whether key players change over time and the reasons for that; (iii) acknowledge patients and families as co-creators of resilience and assess the nature of their social interactions with staff; (iv) evaluation of positive and negative implications of being a key player, from the perspectives of job satisfaction and workload; (v) develop and assess practical improvement interventions to reduce the system’s reliance on key players, evaluating.

Using the same intesive care unit and the survey used for the second chapter, the third chapter of this thesis contemplates the specific objective (ii), and presented an approach to develop and interpret multilayer networks in light of resilience engineering. As resilient performance is influenced by social interactions of several types, this chapter analysed the combination of four layers corresponding to the four abilities of resilient systems: monitor, anticipate, respond, and learn. The proposal is applied in a 34-bed intensive care unit. To map relationships between actors in each layer, a questionnaire was devised and answered by 133 staff members, including doctors, nurses, nurse technicians, and allied health professionals. Two multilayer networks were developed: one considering that actors are 100% available and reliable (work-as-imagined) and another considering suboptimal availability and reliability (work-as-done). The multilayer networks were analysed through actor-centred (Katz centrality, degree deviation, and neighbourhood centrality) and layer-centred metrics (inter-layer correlation, and assortativity correlation). Strengths and weaknesses of social interactions at the ICU are discussed based on the adopted metrics.

From a multilayer perspective, the next chapter use a new survey and another Intensive care unit, focusing on taks analysis, instead of key player and multilayer. This next chapter also presented a new a shoter version of a social network survey, with less actors than the second and the third chapter, but it also brings a second survey together. As for the fourth chapter of this thesis contemplates the specific objective (iii), with the law of requisite variety we presented a practical operationalization in the human factors field, translating complexity theory into a method that can be used by practitioners and researchers. In the context of regulated process and actors' contribution to resilient performance, this contribution is regarded as a proxy of actors' centrality in social networks. Task risk was assessed based on frequency, probability, and severity estimates, whose product generates a risk score for each task. In turn, a resilience score was produced for each actor, combining indicators derived from social network analysis: three related to the actor's centrality in social networks, and two related to the actor's availability and reliability during the social interactions. The proposed approach was applied to an intensive care unit (ICU), in which 56 staff members answered the survey questionnaire that gave rise to the risk and resilience scores.

5.2 LIMITATIONS

In the first paper, presented in the chapter 2, the first limitation is that no distinction was made of the adopted means for social interactions, whether face-to-face or through electronic devices – these two options may have different impacts on the availability and reliability of some players. Second, a broad investigation of contextual factors was not conducted, being limited to those considered in the questionnaire. A third limitation stems from the cross-sectional nature of this study. However, longitudinal SNA studies are methodologically challenging as it is difficult to ensure statistical power to make comparisons between evolving networks. In addition, staff turnover in certain settings imposes additional challenges in the way of obtaining meaningful studies.

In the second paper, presented in the chapter 3, there was no primary qualitative data collection, which could have offered additional insight into the underlying reasons for the observed performance. Second, the pioneer nature of this research in terms of applying multilayer network analysis in resilient healthcare, hindered comparative analysis with other contexts. Third, while the response rate to the questionnaire survey was high (66.2%), some important actors may have been missed out. Fourth, social interactions have other dimensions not explored in this study, such as their timing, duration, and workload implications.

In the third paper, presented in chapter 4, the limitation, our metrics, task risk, and resilience score, were derived from perceptual surveys, which have well-known limitations - e.g., respondents may be inclined to offer socially acceptable answers. Also, this study reinforced the construct validity of the resilience score. Second, the resilience score, with the corresponding social network metrics, was produced for advice-seeking relationships in general, without focusing on any specific task or problem. A more fine-grained analysis, and other insights, could be obtained if both the resiliemce score and task risk were limited to a narrower scope.

5.3 FUTURE STUDIES

Throughout this study, several opportunities for future research were envisioned, which are: to investigate the key players in a longitudinal study to understand whether actors' centrality and network structures change in face of prolonged crisis and growing use of virtual interactions, as observed during the COVID-19 pandemic and developing multilayer approaches for investigating resilient performance, e.g. by considering interactions between layers composed by nodes at the individual, team, and organizational levels.

Other possible study would be to use other proxy metrics on order to process and controll the variety - e.g., variety of patient profiles and metrics of organizational resilient capabilities that cannnot be tracked down to individual people focusins on different units of analysis – e.g. patient admission or patient discharge instead of several ICU tasks; and to explore the possible moderating role of contextual factors (e.g., technological sophistication of the ICU equipment), on the relationship between process and controller variety. Future work needs to consider other types of attributes that would better capture the dynamic and often chaotic nature of the context of patient profiles and metrics of organizational resilient capabilities. Examples include dynamic or complex attributes that, ultimately, create additional analytic opportunities and can help to gain a more detailed understanding of complex social interactions.