Effects of Physician Collaboration Network on Hospital Outcomes

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Abstract

Previous studies have documented the effect of collaboration among physicians on the effectiveness in delivering health services and in producing better patient outcomes. However, there is no systematic empirical study suggesting the underlying relationship between the collaboration network of physicians and its effect on hospital outcomes (i.e., hospitalization cost and readmission rate). In this study, we first propose a way to capture collaboration network among physicians from their visiting information to patients. Then we explore the effect of different attributes (i.e., degree centrality, betweenness centrality, and network density) of physician collaboration network (PCN) on hospital outcomes. Our results show that degree centrality (i.e., level of involvement) and network density (i.e., level of connectedness) of PCN are negatively correlated with hospitalization cost and readmission rate. In contrast, betweenness centrality (i.e., capacity to control the flow of information) is found positively correlated with hospitalization cost and readmission rate. In their respective hospitals, healthcare managers or administrators may follow our research findings to reduce cost and improve quality (i.e., lower readmission rate).

Keywords: Physician collaboration network; readmission rate; hospitalization cost; network attribute.

1 Introduction

Collaboration, the most important aspect of team care (Cunningham and Dillon, 1997), is an intricate concept with multiple attributes including sharing of planning, making decisions, solving problems, setting goals, assuming responsibilities, working together cooperatively, and communicating and coordinating openly (Luuukkonen et al., 1993, Beaver and Rosen, 1978). It generally refers to individual and organizational approach of ‘working together’ to address problems and deliver outcomes that are not easily or effectively achieved by working alone (Hoffman, 1998). According to De Vreede and Briggs (1995), collaboration is a recurring process where two or more people or organizations work together towards common goals.

Collaboration enables individuals and organizations to work together more effectively and efficiently. Collaborative practice is now central to the way we work, deliver services, and produce innovations. Collaborative relationships among individuals are highly celebrated in organizations because the synergies realized by combining multi-dimensional efforts and diverse expertise produce benefits greater than those achieved through individual effort (Knoben and Oerlemans, 2006, Uddin and Hossain, 2011b).

Collaboration is characterized by highly interdependent relationships among participating individuals or organizations (Erdoes et al., 1973). The behavior and role of participants in a collaborative environment are greatly influenced by the current level of fulfillment of the desired outcomes (Huxham and Vangen, 2000). Participants may have to radically alter the way they think, behave, and operate to cope up with the demands and challenges of a highly dynamic collaborative environment. For example, physicians may set up an initial treatment plan (e.g. medical check-up routine, drug intervention plan, and any possible surgery plan) for a hospitalized chronic patient suffering from asthma and diabetes. If that patient has a sudden ‘massive heart attack’ then physicians have to change the initial treatment plan for effective and faster disease recovery.

As a facilitator to accelerated group performance, the importance of collaboration has been identified by many scholars in diverse research areas such as virtual research and development (R&D) organizations (Ahuja et al., 2003), scientific network among authors (Huang et al., 2008), evaluation of creative performance (Liu et al., 2005), and performance analysis of physical task and foreign markets (Newman, 2001, Newman, 2004). In the context of healthcare service providers or hospitals, collaboration among different healthcare professionals is recognized as a catalyst to improved patient outcomes such as less hospital length of stay and hospitalization cost (Cowan et al., 2006, Tschannen and Kalisch, 2009, Uddin and Hossain, 2011a), less death rate (Knaus et al., 1986), and higher satisfaction (Baggs et al., 1999, Lindeke and Sieckert, 2005). In healthcare settings, collaboration allows input from multiple professions (e.g. nurse, physicians) which could produce decisions leading to better patient outcomes because those decisions are based on more complete information.

The context of this study is the healthcare service providers or hospitals. It can be conceptualized that physicians collaborate with each other and with other hospital staff (e.g. nurses) in order to provide effective services to hospitalized patients. Based on the patient...
condition and unavailability of their colleagues, physicians might seek advices or suggestions from other physicians working in different workplaces. Eventually, this type of medical practice culture inside healthcare service providers or hospitals develops a professional collaboration network among physicians, which we termed as 'Physician Collaboration Network, PCN'.

In recent years, there has been an increased trend on clinical measures of quality, such as mortality and morbidity, to study collaboration and coordination in healthcare organizations (Kalkanis et al., 2003, Sylvia et al., 2008). However, to quantify the patient perception of quality is not an easy job, and could result different responses from different patients for similar services. Moreover, not all hospital admissions are life-threatening. Some of them have very low or zero chance of death, such as a hospital admission for a broken hand. In this study, we analyze how hospitalization cost and readmission rate are affected by different network attributes of PCN. Bavelas (1950) first, subsequently by many researchers (Guetzkow and Simon, 1955, Shaw, 1956), show that network attributes of any collaboration network (e.g., PCN) have impacts on its outcomes (e.g., readmission rate). The following two questions motivate this research:

(i) How does the different network structure of PCN affect hospitalization cost and readmission rate?
(ii) What structural properties of PCN are related to hospitalization cost and readmission rate?

2 Review of Collaboration Research within Healthcare Context

There are numerous studies in current literature exploring the effect of collaboration among healthcare professionals on patient outcomes and hospital performance. Most of these studies examine the impact of nurse-physician collaboration on patient outcomes. One classic study, led by Knaus and his team, identifies a significant relationship between the degree of nurse-physician collaboration and patient mortality in intensive care units (Knaus et al., 1986). They study treatment and outcome in 5030 incentive care unit patients, and find that hospitals where nurse-physician collaboration is present report mortality rate of 41%, which is lower than the predicted number of patient deaths. Conversely, hospitals that are noted for poor communication among healthcare professionals exceed their predicted number of patient deaths by 58%. In a two group quasi-experiment on 1207 general medicine patients \((n = 581)\) in the experimental group and \(n = 626\) in the control group, Cowan, Shapiro et al. (2006) notice average hospital length of stay is significantly lower for patients in the experimental group than the control group (5 vs. 6 days, \(P < .0001\)) which contributes a 'backfill profit' of US$1591 per patient to hospital. There are other studies that also highlight the importance of collaboration among healthcare professionals for better patient outcomes. In particular, greater collaboration between nurse and physician has been found to expedite hospital performance which is measured in terms of increased patient and professional satisfaction (Melin and Persson, 1996, Luukkonen et al., 1992), lower nursing turnover (Melin and Persson, 1996), and lower job stress (Melin and Persson, 1996, Luukkonen et al., 1992).

Sommers, Marton et al. (2007) examine the impact of an interdisciplinary and collaborative practice intervention involving a primary care physician, a nurse, and a social worker for community-dwelling seniors with chronic illnesses. They conduct a controlled cohort study of 543 patients in 18 private office practices of primary care physicians. The intervention group receives care from their primary care physician working with a registered nurse and a social worker, while the control group receives care as usual from primary care physician. They notice that the intervention group produced better result to readmission rate and average office visits to all physicians. Moreover, the patients in the intervention group report an increase in social activities compared with control group’s decrease. There are other studies emphasizing collaboration for effective patient outcome across professional boundaries within hospitals. By analyzing data collected from 105 interviews (with 40 physician, 32 case managers, 23 physician office staff, 8 administrators, and 2 case assistants), Netting and Williams (2005) argue that there is a growing need to collaborate and communicate across professional lines rather than make assumptions about who can do what for better patient outcomes, professional satisfaction, and hospital performance.

From the review of collaboration literature in healthcare context, it is evident that some studies have given emphasis on nurse-physician collaboration, while some others have given importance to physician collaboration with all healthcare professionals (e.g. social worker, hospital administrator, and case managers) for better patient outcomes and hospital performance. However, studies to date have not considered a network-level analysis of physician-physician collaboration to understand its effect on hospital performance. In this study, we analyze physician collaborative network (PCN) to understand hospital performance.

3 Physician Collaboration Network and Research Model Development

PCNs evolve over time at each hospital. In this study, we assume that collaborations among physicians emerge when they visit common hospitalized patients. Therefore, when physicians visit common patients within the same hospital or healthcare organization PCN emerges among them. Figure 1 illustrates an example of such a PCN construction. In hospital H1, patient Pa1 is seen by Ph1, Ph2 and Ph4 physicians, and physician Ph2, Ph3 and Ph4 visit patient Pa2. This is depicted in the patient-physician network as in Figure 1(a). The corresponding PCN for this patient-physician network is demonstrated in Figure 1(b). In this PCN, there are network connections with weight 1 between Ph1 and Ph4, between Ph1 and Ph2, and between Ph2 and Ph3 because they visit only one common patient. The weight of the link between Ph2 and Ph4 is 2 as they have two common patients.

In constructing PCN from patient-physician network, for each patient actor we first find out all physician actors
who are connected with that patient actor. Then, we add 1 in the corresponding physician-physician adjacency matrix X. We follow this process for all patient actors of a patient-physician network.

The principal goal of this study is to investigate the impact of the attributes of PCN on hospitalization cost and hospital readmission rate. With that purpose, we propose a research model (see Figure 2) where network measures of PCN are considered as independent variables, and hospitalization cost and hospital readmission rate are taken as dependent variables. The selection of network measures of PCN is guided by two network theories: (i) Bavelas’ Centralization Theory (Bavelas, 1950); and (ii) Freeman’s Centrality Theory (Freeman, 1978). These two theories can explain structural influences of collaboration and communication network on group performance.

The approach for constructing PCN as illustrated in Figure 1 defines a link (with weight 1) between two physicians when they visit one common patient. If two physicians have two common patients then the weight of the link between them will be 2 and so on. This means the PCNs evolved over time within hospitals are weighted networks. Thus, we have to consider approaches that are suitable for weighted networks to quantify network variables of our proposed research model.

### Degree Centrality

**Definition**

Degree centrality is defined by the number of direct links that a particular node has in the network (Newman et al., 2002). It can be defined both at actor-level and at network-level. As we analyze PCNs having different sizes in this research, the network-level quantification for degree centrality is considered. The equation for network-level degree centrality of a weighted graph with n actors:

$$\text{Degree-Centrality} = \sum_{i=1}^{n} \sum_{j=i+1}^{n} w_{ij} / n * (n-1) \quad (1)$$

Where, \(w_{ij}\) is the weight of the link between actor \(i\) and \(j\).

### Betweenness Centrality

Like degree centrality, betweenness centrality can be measured from the perspective of both node-level and network-level perspective where the first one is used to measure the later one. In node-level, betweenness centrality views an actor as being in a favoured position to the extent that the actor falls on the shortest paths between other pairs of actors in the network. That is, nodes that occur on many shortest paths between other pair of nodes have higher betweenness centrality than those they do not (Freeman, 1978). The node-level betweenness for a node \(n_b\) (i.e. \(C_B(n_b)\)) can be represented by the following equation (Wasserman and Faust, 2003):

$$C_B(n_i) = \sum_{j<k} g_{jk} / g_{jk} \quad (2)$$

Where, \(i \neq j \neq k; \ g_{jk}(n_i)\) represents the number of shortest paths linking the two actors that contain actor \(i\); and \(g_{jk}\) is the number of shortest paths linking actor \(j\) and \(k\).

To compare betweenness across different networks, network-level betweenness is used. It represents the average difference between the relative centrality of the most central node (\(C_B(p^*)\)), and that of all other nodes (Freeman, 1977):

$$C_B = \sum_{i=1}^{n} [C_B(p^*) - C_B(p_i)] / n * (n-1) \quad (3)$$

Where, \(C_B(p^*)\) is the largest realized actor betweenness index for the set of \(n\) actors, and \(C_B(p_i)\) is the node-level betweenness for actor \(i\).

### Network Density

The density measure represents the proportion of existing links in a network relative to the total number of possible ties among all the network actors (Wasserman and Faust, 2003). The density value for a network is 1 only when all the nodes of that network are connected with each other. Conversely, for a completely sparse network, the density value is 0. In an undirected network of size \(n\), theoretically there are \(n^n(n-1)/2\) possible links among its \(n\) nodes. Thus, mathematically, density can be defined as:

$$\text{Density} = \sum_{i=1}^{n} \sum_{j=i+1}^{n} w_{ij} / n * (n-1) \quad (4)$$

Where, \(w_{ij}\) is the weight of the link between actor \(i\) and \(j\).
Dependent Variables

In this research, we consider hospitalization cost and readmission rate as dependent variables. PCNs evolve for each particular type of disease during the course of providing healthcare services to patients within each hospital. Some of these patients might need readmission for the same disease. We use this information as one of the independent variables. To measure hospitalization cost, which is utilized as another dependent variable in our proposed model, of a particular PCN we consider the hospitalization cost of only those patients who are belong to that PCN, and then calculate the average of hospitalization cost of all those patients.

4 Methodology

4.1 Research Dataset

In this research, to test our proposed hypotheses we consider health insurance claim data from a non-profit Australian health insurance organization, hospital contribution fund (HCF). It includes members claim data from January 2005 to February 2009. This dataset contains information about three different categories of claims: ancillary claim, medical claim, and hospital claim. Ancillary claims are auxiliary claims for medical services, e.g., dental, optical, physiotherapy, dietician, and pharmaceutical. All claims coming from specialist physicians except of the ancillary type are medical claims. The claims for the services provided to hospitalized patients are considered as hospital claims. In general, patients have medical claims, hospital claims, and very few ancillary claims for their admissions to hospitals.

In our dataset, there are about 14.87 million ancillary, 8.98 millions medical, and 3.1 millions hospital claims that HCF received from 2507 hospitals for the health services provided to its 0.44 million members. As people have hospital admissions for a wide range of illness and patients with a particular disease need to be seen by particular specialist physicians, different types of PCNs (e.g., a PCN for knee-surgery patient, and a PCN for heart-attack patient) evolve inside a hospital for hospitalized patients. In this study, we consider PCNs only for THR patients from 85 different hospitals where at least 5 THR patients get admitted during the data collection period. In these 85 hospitals, there are 2229 patients get admitted during our data collection period. These patients lodge in total 1383 ancillary, 65871 medical, and 23369 hospital claims. None of the patients of our research dataset died during the hospitalized period.

4.2 Construction of PCN

From the ‘medical claims’ details of HCF dataset, we can trace how many physicians visit a particular hospitalized patient because physicians make a ‘medical claim’ to HCF for every single visit to hospitalized patients. Based on this information and by applying the PCN development concept of Figure 1, we figure out the structure of PCN of each hospital for THR patients.

Figure 3: Construction of PCN from research dataset. The red circle represents physician and the yellow triangle represents patient.

4.3 Method of Analysis

Using UCINET-6 (Borgatti et al., 2002), we first calculate the four network measures of our proposed model from the PCNs that are constructed from our research dataset. Second, we apply correlation test to assess relations of four network measures with hospitalization cost and readmission rate. As it is revealed that histograms for these four network measures do not follow a complete normal distribution curve, we choose a non-parametric (i.e. Spearman test) correlation test.

5 Results

By inferring the Spearman coefficient values of Table 1 and t-test results from Table 2, we reach to the following statements:

(i) Degree centrality of PCN has negative correlation with both Hospitalization Cost and Readmission Rate.

We find that degree centrality of PCN is negatively correlated with hospitalization cost (rho = -0.212, p<0.05 at 1-tailed) and readmission rate (rho = -0.366, p<0.01 at 1-tailed). A decrease in degree centrality produces a downturn for both hospitalization cost and readmission rate. That means high degree centrality among physicians makes healthcare organizations possible to provide healthcare services to hospitalized patient with efficient cost structure (i.e., low cost) and better quality (i.e., low readmission rate). As degree centrality represents actors’ involvement in a given network higher level of physicians’ participation should be encouraged in hospital settings.

(ii) Betweenness centrality of PCN has positive correlation with both Hospitalization Cost and Readmission Rate.

The Spearman correlation test shows that betweenness centrality of PCN is positively correlated with hospitalization cost (rho = 0.264, p<0.01 at 1-tailed) and readmission rate (rho = 0.460, p<0.01 at 1-tailed). As it is always expected to have low hospitalization cost and readmission rate, this result indicates that high betweenness centrality is not conducive for healthcare service providers or hospitals. PCNs that do not have stronger level of capacity to control the flow of information should be highly encouraged in any hospital.
setting as *betweenness centrality* indicates the capacity to control flow of information.

**(iii) Density of PCN has negative correlation with both Hospitalization Cost and Readmission Rate.**

Results indicate that density of PCN is negatively correlated with hospitalization cost (rho = -0.228, p<0.05 at 2-tailed) and readmission rate (rho = -0.282, p<0.05 at 2-tailed). Both hospitalization cost and readmission rate of a hospital change inversely with the change in the density of the PCN of that hospital. Because density indicates the level of connectedness among actors in a given network PCNs having higher level connectedness among physicians should be celebrated in a hospital setting.

### Table 1: Spearman correlation coefficient among our research variables

<table>
<thead>
<tr>
<th></th>
<th>Hospitalization Cost</th>
<th>Readmission Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degree Centrality</td>
<td>-0.212</td>
<td>-0.366</td>
</tr>
<tr>
<td>Betweenness Centrality</td>
<td>0.264*</td>
<td>0.460*</td>
</tr>
<tr>
<td>Network Density</td>
<td>-0.228</td>
<td>-0.282</td>
</tr>
</tbody>
</table>

* Correlation is significant at the 0.01 level (2-tailed)
** Correlation is significant at the 0.05 level (2-tailed)

### 6 Discussion

For any PCN, it is desirable to have low hospitalization cost and readmission rate. Therefore, negative correlations between any pair of independent and dependent variables of our research model represent a way to control these two dependent measures in positive direction, and vice versa.

We discover that degree and density (first and third findings) of PCN have negative correlation with hospitalization cost and readmission rate. Having professional relation with more colleagues (i.e., higher degree) makes it easier for an individual physician to share medical knowledge effectively. The importance of sharing of physician knowledge is also identified by present healthcare literature. Ryu et al. (2003), for example, find that sharing knowledge of physicians within hospitals is very critical to the success and survival of the hospital organization. According to our first finding, healthcare managers or administrators should encourage the involvement of more physicians for the treatment of hospitalized patients in order to reduce hospitalization cost and readmission rate. The measure density is the proportion of possible links that are actually present in the network. In a dense PCN, increased number of links exists among physicians. This means higher degree also ensures increased density. A PCN could have high degree centrality when its member physicians work in small well connected groups though this type of PCN does not confirm a higher density. Thus, our third finding suggests that physician should not work in small groups; instead they need to work with more of their colleagues. This will increase both degree and density, which eventually enable faster sharing of known knowledge (Ryu et al., 2003), and reduce hospitalization cost and readmission rate.

On the other hand, we notice that betweenness (from second finding) of PCN has positive correlation with both hospitalization cost and readmission rate. From the perspective of PCN structure, at network-level, high betweenness centrality indicates big differences in the node-level betweenness centralities between the most central node and that of all other nodes. That means denominator of equation 3 will be high if the network-level betweenness is high. Thus, our result regarding betweenness centrality indicates that big differences among the node-level betweenness centrality scores in PCN are not favourable to the dependent variables (i.e., hospitalization cost and readmission rate) of our proposed model. A big fluctuation among betweenness centrality scores in any network reflects an unequal participation, and uneven collaboration and communication control of its member nodes (Freeman, 1978). In this type of network, only a small number of actors play major collaboration and communication role. Therefore, in their corresponding hospitals, healthcare managers or administrators have to make sure the equal participation of physicians in PCNs.

PCN, hospitalization cost and readmission rate are the three key measures of this study. First, we construct PCN from the information of physicians’ visits to patients during their hospitalization period. We assume that collaboration emerges between two physicians when they visit a common patient. It is standard professional practice around the world that when physicians visit patients they give advice or suggestions to patients based on patient health condition and previous medication history deposited in the patient log book. All previous advice or suggestions by any physician to a patient have been taken into consideration during any subsequent physician visit to that patient. This kind of practice culture in healthcare organizations or hospitals establishes the validity and reliability of the construction process of PCN, and the generalizability of our research findings. Second, we consider hospitalization cost and readmission rate as dependent variables in our proposed model. The use of readmission rate as an outcome measure has well acceptance in healthcare literature (Chen et al., 2010, Ross et al., 2010). Though hospitalization cost is not an well accepted outcome measure in healthcare literature (Chen et al., 2010), coupled with readmission rate, it could be a potential outcome measure.

### 7 Conclusion

This study is motivated by two research questions: “How does the different network structure of PCN affect hospitalization cost and readmission rate?” and “What structural properties of PCN are related to hospitalization cost and readmission rate?” In line with these research questions, we find that the PCNs which are characterized by higher degree centrality, lower betweenness centrality, and higher network density are conducive to hospitalization cost and readmission rate.

In this research, we propose a new way to capture the collaboration network among physicians within healthcare providers or hospitals. Further, we investigate
PCN using social network approach of network analysis to explore the impact of the attribute of PCN on hospitalization cost and readmission rate. To our knowledge this is the first study which takes the initiative to understand the impact of physicians’ collaboration within hospitals by applying structural network methods and measures.

Reference


