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Clique and Clan Analysis of Patient-Sharing Physician Collaborations

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Abstract**—**The collaboration among physicians during episodes of care for a hospitalised patient has a significant contribution towards effective health outcome. This research aims at improving this health outcome by analysing the attributes of patient-sharing physician collaboration network (PCN) on hospital data. To accomplish this goal, we present a research framework that explores the impact of several types of attributes (such as clique and clan) of PCN on hospitalisation cost and hospital length of stay. We use electronic health insurance claim dataset to construct and explore PCNs. Each PCN is categorised as 'low' and 'high' in terms of hospitalisation cost and length of stay. The results from the proposed model show that the clique and clan of PCNs affect the hospitalisation cost and length of stay. The clique and clan of PCNs show the difference between 'low' and 'high' PCNs in terms of hospitalisation cost and length of stay. The findings and insights from this research can potentially help the healthcare stakeholders to better formulate the policy in order to improve quality of care while reducing cost.

Keywords**—**Clique, clan, electronic health records, physician collaboration.

I. Introduction

COLLABORATION is a combined process of multiple attributes including sharing of planning, decision-making, problem-solving, fixing goals and working together cooperatively. It enables individuals or organisations to work together in an effective and efficient way which would otherwise not be possible by an individual [1]. Collaborative relationship among people is highly valued in organisations because the synergies realised by diverse expertise produce benefits more than those achieved through individual effort [2].

In the literature, the importance of collaboration to improve the performance has been identified by researchers in various research areas, such as scientific network among authors [3], obesity research collaboration [4], virtual research and development organisations [5], evaluation of creative performance [6], and performance analysis of physical task and foreign market [7]. In the context of healthcare service providers (e.g., hospitals), collaboration among physicians has been found very important for increasing patient consciousness, producing better health outcomes (e.g., less length of stay in hospital, lower hospitalisation cost, lower mortality rate and higher satisfaction) and improving quality of care [8], [9].

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In healthcare settings, collaboration allows multiple inputs from various sources (e.g., physicians and nurse) that could produce more accurate decisions leading to better patient outcomes [9]. Uddin et al. [10] proposed a framework that uses details of professional interactions (e.g., physician to physician link) to learn about effective healthcare collaboration and coordination using social network. They analysed patient-centric care coordination and PCNs as a social network. The use of measures and methods of social network analysis has gained wide acceptability in other research areas (e.g., crisis communication network [11]). To our knowledge, there is no study that uses sub-group analysis (i.e. clique and clan) of PCNs to seek higher quality of care and better outcomes. This study aims to fulfil this gap of the literature and provides a better understanding about the effective and efficient physician collaboration structure.

This study focuses on physician collaborations in hospital context where they provide healthcare services to patients during their admission periods. When a patient is admitted, the physicians within the same or different hospitals collaborate to provide required healthcare services. Depending on the patient's condition and availability of their colleagues, physicians might seek suggestions from other physicians working in different hospitals. Consequently, this type of medical practice develops a professional collaboration network among physicians. This study names this network as patient-sharing PCN.

As evident in the literature, there is an increased trend on using clinical measures of quality (e.g., morbidity and mortality rates) to study coordination and collaboration in healthcare contexts [12], [13]. However, it is often difficult to quantify the patients' perception of quality as it could give different subjective results from patients receiving similar or same services. Some hospital admissions are not life-threating; for example, a hospital admission for a broken hand. For such admissions, the clinical measure of mortality is not suitable to evaluate the quality of care. At first, Bavelas [14] and then other researchers [15], [16] show that the attributes of any collaboration network (e.g., PCNs) have impact on different objective outcomes (e.g., readmission rate in the context of hospital admissions). In this research, we study the patient-sharing PCNs evolving within hospitals using sub-group analysis in order to explore the effect of different network attributes of such networks on hospitalisation cost and hospital length of stay.

II. Research Method

A. Sub-Group Analysis

1. Clique and N-Clique

In graph theory, a cluster concept is given by the *clique* of a graph *G*. A *clique C* is a maximal complete subgraph of a graph *G*. It represents clusters of similar kind of elements. For example, in social networks, a *clique* is a group of people who are more closely and intensely tied (such as through friendship and acquaintance) with each other [17]. At the most general level, a *clique* is a subset of a network in which actors are more closely and intensely tied (or linked) to one another than they are to other members of the network. A *clique* can also be thought as a collection of actors, all of whom *choose* each other and there is no other actor in the network who also *chooses* and is *chosen* by all members of the clique [18], [19].

The *clique* definition for the strict condition of maximal fully connected subgraph can be too strong for many purposes. It insists that any two members of the clique must have a direct relationship with each other. To relax this criterion, *n-clique* concept is introduced by Luce [20]. An *n-clique* of a graph *G* is a maximal subset of vertices where distance d_G between any two vertices *u* and *v* is defined by:

$$d_G(u,v) \leq n$$

In Fig. 1, actors *B*, *D*, *E*, *F* and *G* form a *2-clique* as they are connected among themselves at a maximum distance of 2. A *2-clique* is a subgroup in which all the group members are not required to be adjacent, but all of them would be reachable through at most one intermediary [19].

Since a network with higher number of actors is likely to form larger number of cliques compared to its counterparts, we divide the number of cliques by the number of actors to generate a normalised clique value for each PCN considered in this study.

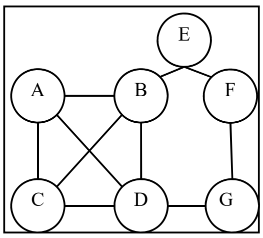

Fig. 1 Illustration of clique (*ABCD*), 2-clique (*ABCDEG* and *BDEFG*) and clan (*BDEFG*)

2. Clan

The trend of *n-clique* method is to find a long group rather than the tight and discrete one of the maximal methods, while the tightness in the group is essential to applications in social networks. In addition, members of *n-clique* can be connected by intermediate actors who are not members of the clique. These are often problems for most sociological applications. To solve them, Alba [21] first introduced the concept of a '*sociometric clique*', which was renamed to *n-clan* by Mokken [17]. An *n-clan* is an *n-clique* with diameter *D* which is less than or equal to *n*.

In Fig. 1, one of the two *2-clique* is *ABCDEG*. In this *2-clique*, the actor *E* is connected to the actor *G* with a minimum distance of *2* through the node *F* which is not a member of this *2-clique*. Although there are two 2-Cliques (i.e., *ABCDEG* and *BDEFG*), only one (i.e. *BDEFG*) satisfies the restriction of the *n-clan* approach.

B. Research Data

The health insurance claim data from a non-profit Australian health insurance organisation (i.e., The Hospital Contribution Fund) has been used to achieve the research goals of this study. The data include the members' claim data from January 2005 to February 2009. It consists of three different types of claims: ancillary claim, medical claim, and hospital claim. Ancillary claims are auxiliary claims for medical services like dental, optical, physiotherapy, dietician, and pharmaceutical. The claims from specialist physicians other than the ancillary type are medical claims. All other claims for the services that patients received during their hospitalisation period are considered as hospital claims.

The dataset consists of about 14.87 million ancillary, 8.98 million medical and 3.1 million hospital claims received from 2507 hospitals for 0.44 million members. Admitted patients can have a wide range of diseases and patients with a specific disease needs to be seen by particular specialist physicians. Thus, different types of PCNs (such as, PCN for heart-attack patient or PCN for diabetes patient) exist inside the hospitals for hospitalised patients. This study considers PCNs only for total hip replacement patients from 53 hospitals. None of the patients of our dataset died during the hospitalised period.

We used Medicare Benefits Schedule (MBS) codes [22] to extract physician visiting information and admission details of the target patients (i.e., hip replacement patients) admitted in any of the 53 hospitals considered in this study. The MBS coding scheme was developed by the Australian Department of Health and Aging [22]. Every year, this coding method is reviewed and updated, if required, in order incorporate any new medical procedures discovered in medical science. In Australia, this coding scheme is followed by most healthcare service providers.

C. Research Analysis Framework

The goal of this study is to analyse the impact of PCN attributes on hospitalisation cost and hospital length of stay. The overall procedure of research analysis followed in this study is illustrated in Fig. 2. The attributes of PCN, e.g., clique and clan are considered as independent variables, whereas hospital length of stay and hospitalisation cost are considered as dependent variables. This study first constructs and categorises PCNs from the research dataset used in this study. It then calculates the network measures of PCNs using the UCINET software tool [23]. Finally, the statistical *t-test* had been used to assess relations of network measures with hospitalisation cost and hospital length of stay.

This study analysed 53 patient-sharing PCNs. These networks had been developed in 53 different hospitals through physicians' visits to patients during their hospitalisation period. Each PCN is a sample of this study and the sample size of this study is 53. Several hip replacement patients ranging from 6 to 100 were admitted to each of these 53 PCNs. To calculate the hospital length of stay for a PCN, this study considered the average of length of stay values for all hip replacement patients who were admitted to the corresponding hospital of that PCN. A similar approach was followed to quantify hospitalisation cost for each PCN.

D. Construction and Categorisation of PCN

PCNs are generated through the collaboration of physicians in hospital settings over time. This study assumes that collaboration among two physicians emerges when they both visit a common patient during his/her hospitalisation period. An illustration of a PCN construction approach considered in this study is shown in Fig. 3. As illustration in this figure, patient *Pa.1* is seen by three different physicians - *Ph.1*, *Ph.2* and *Ph.3*. Physician *Ph.2* and *Ph.3* also visit patient *Pa.2*. The resultant patient-physician network is depicted in the patient-physician network as shown in Fig. 3 (b). Finally, the corresponding PCN for the patient-physician network is illustrated in Fig. 3 (c). In this PCN, the edges between *Ph.1* and *Ph.2*, and between *Ph.1* and *Ph.3* have a weight of 1 indicating that each pair of physicians visit only one common patient, whereas the edge weight for the link between *Ph.2* and *Ph.3* is 2 which indicates that they have two common patients.

Using the percentile rank statistics, this study categorised each PCN as '*low*' and '*high*' in terms of hospitalisation cost and hospital length of stay. For each of these two criteria, PCNs having a lower than or equal value of 40th percentile is considered as '*low*' PCN. On the other hand, PCNs having a higher than or equal value of 60th percentile is considered as '*high*' PCN.

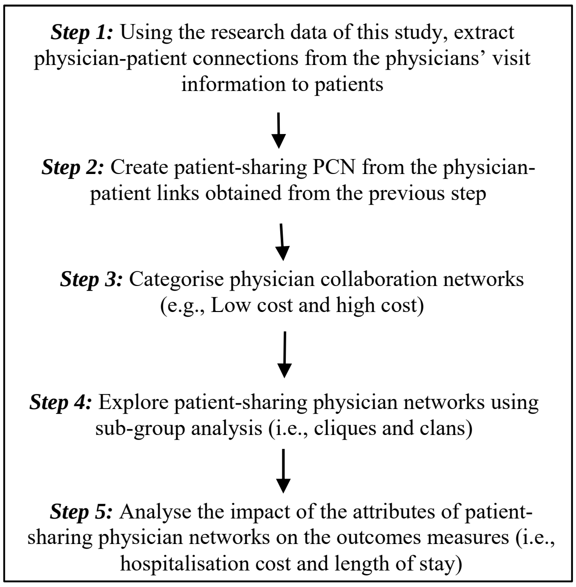

Fig. 2 Research analysis procedure followed in this study

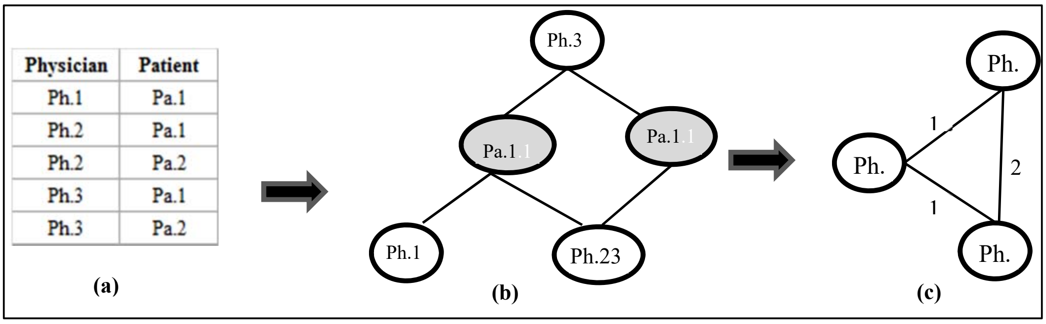

Fig. 3 Construction of a PCN based on an abstract data set: (a) information of physicians' visits to patients; (b) the corresponding patient-physician connections; and (c) the resultant PCN

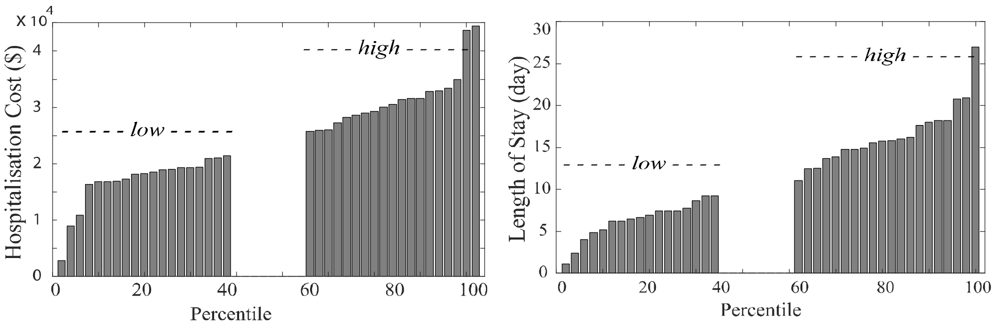

Fig. 4 Distributions of two extreme conditions: 'low' (≤40 percentile) and 'high' (≥60 percentile)

E. Statistical Analysis

This study used *t-test* for statistical data analysis. The *t-test* compares the average between two unrelated groups on the same independent and dependent variable and tells us if the groups are different from each other or not. The *t-statistics* (i.e., *t-value*) is calculated by dividing the mean difference by its standard error. In general, the acceptable *t-value* is greater than +2 or less than -2. The higher *t-value* indicates the more difference between groups, whereas a lower *t-value* indicates the more similarity between groups [24]. Every *t-value* has a *p-value* that indicates the significant difference between the means of two groups. In the literature, the *t-test* method is mostly used to compare the *t-* and *p*-value of different measures [25], [26].

III. Results and Discussions

The distributions and their associated range values for '*low*' (≤40 percentile) and '*high*' (≥60 percentile) values for the three criteria (i.e., hospitalisation cost and hospital length of stay) are shown in Fig. 4. According to Fig. 4 (a), the range for the category of '*low*' hospitalisation cost is $2,753 - $21,718 and for the '*high*' category is $25,636-$44,428. As presented in Fig. 4 (b), the range for the '*low*' length of stay is 1-9 days and for the '*high*' length of stay is 12-27 days.

At this point, we describe the *t-test* results regarding the PCN-related measures (clique and clan) on the hospitalisation cost and hospital length of stay. The findings of this study are illustrated in Table I. In this study, the social network analysis (SNA) measures (i.e., 1-clique, 2-clique,1-clan and 2-clan) are used as independent variables in *t-test*, whereas hospitalisation cost and hospital length of stay are used to categorise (as '*low*' and '*high*') network measures.

In Table I, the level of significance of *t-test* was found to be less than 0.05 ($p<0.05$) between low-hospitalisation cost and high-hospitalisation cost and between low-length of stay and high-length of stay for the clique and clan measures. This level of significance means that there is a significant difference between them. Thus, the network structure of patient-sharing physician collaborations affects the hospitalisation cost and hospital length of stay.

In respect of hospitalisation cost and hospital length of stay, the '*low*' PCNs have more cliques and clans compared to their counterparts, as per the mean values of Table I. This indicates that in such '*low*' PCNs physicians are connected into small groups through sharing common patients. Working into small groups over the time allows physicians to have more discussions about their shared patients. This could lead to the positive hospitalisation cost and length of stay outcomes as found in this study. Fig. 5 illustrates pictorial differences between a '*low*' and '*high*' PCN from the research data. The '*low*' PCN (left one) has less number of nodes that are almost evenly connected. This leads to the presence of higher number of cliques and clans in this PCN. The '*high*' PCN (right one) has higher number of nodes that are mainly grouped into three clusters. Although there could be higher number of cliques and clans within each cluster, the overall number of clique and clan for the entire PCN will be less because of this clustering tendency.

As evident from the sub-group analysis, higher values *2-clique* and *2-clan* are significantly related to lower hospitalisation cost and shorter length of stay. The sub-groups of 2-clique and 2-clan are also a small group, but they usually are formed with more than three actors. Therefore, it can be argued that larger sub-group structures, rather than smaller ones, are related to lower hospitalisation cost and shorter length of stay.

IV. Conclusions

This study proposed a way to explore the effect of different sub-group attributes of PCN on hospitalisation cost and hospital length. The structure of PCNs in respect to sub-group has been found to be related with hospitalisation cost and length. The finding of this study can be used in promoting the physician collaborations structure within the hospitals or health-care service providers.

Like any other research studies, this research has some limitations. First, this study did not consider any other information of patient pre-existing and socio-demographic conditions that could affect the present condition. For example, it is likely that a 75-years old type 1 diabetic patient will incur higher hospitalisation cost for a hip replacement surgery compared to a younger and non-diabetic patient. Second, there could be significant relations between hospitalisation cost and length of stay. This study did not consider such relations in exploring the impact of PCN structures on these three different measures. Finally, this study considered only one type of patients (i.e., hip replacement patients). Consideration of other type of patients (e.g., cancer patient and knee replacement patients) is required to confirm the generalisation of the findings of this study. Regardless of these limitations, our novel analysis showed how the group structure of patient-sharing physician collaborations affects two different healthcare measures of hospitalisation cost and hospital length of stay.

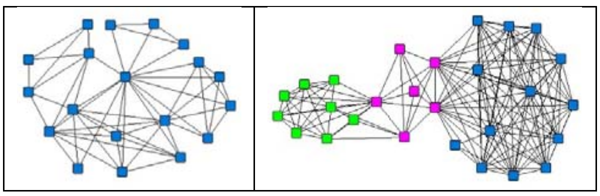

Fig. 5 An example 'Low' (left panel) and 'High' (right panel) PCN in terms of all three measures (i.e., hospitalisation cost and hospital length of stay). The nodes represent different doctor IDs and edges indicate transition between doctors

TABLE I
T-TEST STATSTICS FOR THE ANALYSIS OF EFFECTS OF THE MEASURES OF PCNS ON HOSPITALISATION COST AND HOSPITAL LENGTH OF STAY

		Hospitalisation cost (N_L=19 and N_H=19)			Length of stay (N_L=17 and N_H=20)		
		Mean	*t*	Sig.	Mean	*t*	Sig.
1-Clique	Low	2.87	-0.98	0.334	2.64	-1.01	0.318
	High	6.51			6.24		
2-Clique	Low	0.17	3.58	0.001	0.15	2.21	0.037
	High	0.08			0.09		
1-Clan	Low	2.87	-0.98	0.334	2.64	-1.01	0.318
	High	6.51			6.24		
2-Clan	Low	0.17	3.60	0.001	0.15	2.19	0.038
	High	0.08			0.08		

*. All significance valued are based on 2-tailed. N_L and N_H indicate the number of '*low*' and '*high*' class hospitals based on the corresponding attributes (i.e., hospitalisation cost and hospital length of stay).

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