Abstract

In this study, we introduce a social network-based research framework to explore and model coordination performance in various healthcare settings. In the healthcare environment, different professionals work together in order to provide effective services to patients. This collaborative working environment eventually develops a social network among healthcare professionals. A social network is a social structure made up of a set of actors (e.g., individuals or organisations) and the dyadic ties between these actors. Measures (e.g., centrality and tie strength) of this social network are considered as independent variables in the proposed framework. Performance attributes of coordination (e.g., hospital length of stay, total hospitalisation cost, readmission rate and patient satisfaction) are utilised as dependent variables and socio-demographic characteristics of healthcare providers, healthcare professionals and patients are regarded as moderating variables. We then exercise this research framework in the modeling coordination and performance of a Patient-Centric Care Network (PCCN) which has evolved over time inside a hospital among different healthcare professionals for each patient admission. We find that social network attributes of degree centrality, connectedness and tie strength impact on coordination performance for PCCN. We further note that socio-demographic characteristics of patient age, patient sex and hospital type (i.e., private versus public) moderate the relation between independent and dependent variables for PCCN. We argue that the proposed research framework of this study could be applied in various healthcare settings (e.g., inter-departmental collaboration within hospital and Intensive-Care Unit coordination) to explore and model coordination performance.

Abbreviations: HCF – Hospital Contribution Fund; PCCN – Patient-Centric Care Unit; SNA – Social Network Analysis; THR – Total Hip Replacement.

Key words: coordination performance; patient-centric care network; hospital length of stay; healthcare management; hospitalisation cost.

Introduction

A social network is defined as a collection of individuals, each of whom is acquainted with a subset of others by one or more different types of relations such as friendship, kinship and organisational position. [1] Social Network Analysis (SNA) is the methodical analysis of social networks. The measures and methods of SNA have been utilised extensively in modeling and exploring interactions among individuals and their impact on collaborative performance in diverse contexts such as disaster response, [2] the manufacturing environment [3] and inter-organisational partnerships. [4]
Coordination, the management of task interdependencies, [5] has been shown to enhance performance not only in non-medical settings such as organisational learning [6] and the product development cycle, [7] but also in healthcare settings, particularly chronic disease management and emergency and intensive care. [8] Coordination is very critical to organisations for their smooth running to achieve desired organisational goals. From the perspective of patient perceptions of quality of care, coordination is identified as one of the most important factors. [9] In addition, effective coordination among staff reduces adverse events like unusual death and wrong treatment in the care of hospitalised patients. [10] Coordination is one way that healthcare organisations have attempted to meet the demands they face; for example, demand for improved quality of care and clinical outcomes and demand for a high level of patient satisfaction.

Measuring the coordination performance of any collaborative effort is a challenging task due to difficulties in detecting the type and nature of interactions that exist among actors. In a hospital emergency department, for example, coordination performance can be measured by how quickly actors (eg, doctors, nurses, medical test units and pathology department) in the hospital emergency network exchange information and take immediate actions based on that information for patients’ successful recovery from illness. Similarly, for extreme events such as natural disasters, where different emergency agencies frequently develop formal and informal network relations, coordination may be quantified by how quickly and effectively such an incident is responded to in order to save lives and return a society to a state of ‘business as usual’. [11] Therefore, it is important to find out the key coordination processes and then measure the effectiveness of those processes in order to measure coordination.

Although coordination is not a new concept in the health services research community, it is difficult to quantify the performance of coordination in healthcare organisations. There is evidence in the current healthcare literature where researchers rely on staff perceptions of quality to measure coordination. [12] In recent years, there is an increasing trend in the clinical measures of quality, such as mortality and morbidity [13] and hospital readmissions, [14,15] to study coordination in healthcare organisations. However, to quantify staff perception of quality is not an easy job and could result in different responses from different staff for the same or similar services. Further, not all hospital admissions are life-threatening and there are hospital admissions with very low or zero chance of death such as a hospital admission for hip replacement or for a broken hand. Thus, any construct or measure that is common to all hospital admissions should be considered in quantifying coordination performance for healthcare organisations.

SNA, which provides both a visual and mathematical analysis of network relations, is the mapping and measuring of relationships among actors. [16] It has been successfully applied to evaluate the location of actors in a network. Network centrality or centrality of SNA is a structural attribute of nodes in a network that determine the relative importance of an actor within that network. The centrality measure of an actor in the network is useful to determine their network position. Degree centrality, which is mainly relevant in the study of popularity and activity of actors, [17] is one of the three basic centrality measures of SNA. The number of direct connections that a node has with other nodes in a network determines the degree centrality of that node. This centrality measure has been criticised for considering only the immediate ties that an actor has, rather than indirect ties to all others. Researchers proposed two other centrality measures (ie, closeness centrality and betweenness centrality) to overcome this shortcoming of degree centrality. An actor’s indirect connectivity with all the rest of the actors of a network is represented by closeness centrality; whereas, betweenness centrality indicates an actor’s capacity to control the flow of information in a network. [18]

In this study, we aim to propose a framework, based on SNA methods and measures, for modeling coordination in healthcare organisations or hospitals. Since SNA measures can explore the locations and positions of actors who are working in a collaborative environment, this framework can examine what structural properties of actors, in terms of their network positions, are conducive to coordination performance. This framework can further explore what other structural properties limit group performance. The rest of the paper is organised as follows. In section two, we propose the research framework for modeling coordination in healthcare context. An application of this proposed research framework to the context of a Patient-Centric Care Network (PCCN) is illustrated in section three. Finally, section three discusses the contribution of this study and concludes the paper.

**Research framework: social networks for modeling healthcare coordination**

In general, healthcare organisations are considered to face situations where either stable or uncertain or a combination
Social Networks in Exploring Healthcare Coordination

Figure 1: Proposed social network-based research framework for modeling coordination performance in healthcare environment

of both work requirements is needed for their smooth functioning to promote patient healthcare outcomes. The uncertainty or unpredictability, which entails a higher level of staff interdependencies, [19] comes in large part from the unpredictable arrival of patients in hospital emergency departments and from the variability of patient responses to medical intervention. On the other hand, only stable work requirements are needed for some hospital admissions. For example, patients who need surgery for knee or hip replacement might be best cared for by going through well-planned procedures in an environment where only stable work requirements are required.

In providing healthcare services, different healthcare professionals including nurses and physicians work together. Because of task dependencies, links or ties evolve among those healthcare professionals during the course of providing services to patients. [20] This type of working environment therefore constitutes a social network among them. On the other hand, existing social network theories (ie, Bavelas’ Centralisation Theory [21] and Granovetter’s Strength of Weak Tie Theory [22]) suggest that the structure of network itself, the positions of individual actors within a network and the strength of network relation between actors affect both individual and group performance. Therefore, this social network can be explored using the measures and methods of SNA, which further enables us to examine which structural properties of this social network are conducive to coordination performance and which others limit it. Figure 1 illustrates the proposed research framework of this study. This framework consists of three components: independent variables, dependent variables and moderating variables. The possible hypotheses constructed from this research framework could be based on (i) whether or not the independent variables have an impact on the dependent variables; and (ii) whether or not the moderating variables have the capability to moderate relations between the independent and the dependent variables. SNA measures (eg, degree centrality, closeness centrality and tie strength) are considered as independent variables and performance attributes of coordination (eg, hospital length of stay, total hospitalisation cost, readmission rate and patient satisfaction) are utilised as dependent variables. Socio demographic characteristics of healthcare professional and healthcare service recipients (eg, patients’ age and gender, and hospital type – public and private) could be the possible moderating variables.

This generalised framework could be exercised in different settings of healthcare service providers or hospitals for modeling coordination performance. For example, it can be utilised to explore a collaboration network that evolves among nurses, physicians and other hospital staff including pathologists and technicians. Moreover, this framework could be utilised to explore collaboration networks among physicians in order to examine what type of communication and coordination is conducive to patient outcomes. Furthermore, inter-departmental coordination and collaboration within a hospital organisation could be explored using this framework. This framework could explore, for instance, how well the emergency department of a hospital collaborates with the other departments of that hospital. In the next section, we exercise this research framework in the context of a PCCN that emerges among nurses, physicians and other hospital staff during the course of providing healthcare services to hospitalised patients.
Figure 2: Patient-centric care network (PCCN) that emerges during patient hospitalisation period

Application of proposed research framework:
Patient-Centric Care Network

It can be conceptualised that during the hospitalisation period, patients receive services from different hospital service units. Also, depending on the unavailability of hospital doctors and the patients’ medical condition, patients need to be seen by outside specialist doctors. For instance, a patient might be served by medical test department before going through hip replacement surgery by surgeons or specialist doctors. After surgery that patient could be served by a primary care unit for post surgery care. At this stage, that patient might need to be seen by external doctors depending on their medical condition. This forms a PCCN as illustrated in Figure 2. The one-directional links between patient and different hospital units in this Figure indicate that patients receive medical services from those service units. There are also relations and interdependencies among all hospital departments, as shown by the two-directional dotted line in Figure 2. These types of interdependencies between patient and service units and among different service units impact on both network attributes (e.g., frequency of doctor-visit) and performance measures (e.g., hospital Length of Stay [LOS] and patient satisfaction) of PCCN. Based on the research framework of Figure 1, we propose a model, which is illustrated in Figure 3, to explore the coordination performance of PCCN. In this model we consider the attributes of PCCN as independent variables, patients’ hospital LOS as dependent variable and socio-demographic characteristics of patients and hospitals as moderating variables.

Focusing on effective delivery of health services and patient expectations, researchers have been working to develop coordination models for healthcare providers or hospitals. A number of promising care coordination models are found in the current healthcare literature. Care Transition Model, for example, which provides care across different healthcare settings to patients with chronic or acute illness, shows...
lower hospital readmission rate and less total medical expenses. [23] Another cost-effective patient care model is the Guided Care Model which is a patient-centred, practical and interdisciplinary model for healthcare. This model showed impressive results from small controlled experiments. [14] For the treatment of patients with multiple chronic diseases the Chronic Care Model, which is a team-based approach to organising care, produced reduced mortality with excellent patient satisfaction in an experiment on 2356 patients. [24] There are also healthcare models with creative designs (eg, Virtual Integrated Practice Model) that have been developed to meet standard patient expectations. [25] The purpose of all these patient-centered models is to reduce treatment costs and to improve service quality, patient expectation and satisfaction. However, none of these studies investigates the underlying impact of the attributes of PCCN on hospital coordination performance.

3.1 Model variables

We utilise degree, tie strength and connectedness as independent variables and LOS as a dependent variable in the proposed coordination performance model of Figure 3. The choice of three moderating variables (ie, patient age, patient sex and provider type) in this model is motivated by the present healthcare literature. In a study of 712 hip and knee arthroplasty patients, Husted et al [26] found that the patient characteristic of age associated with hospital LOS and the perceived level of satisfaction. In another study of 16.9 million patients aged 65 or over, Yuan et al [27] noted the correlation between hospital type (ie, not-for-profit versus private) and LOS for the same surgical procedure. LOS also differs for male and female patient suffering from the same disease. For instance, Skobeloff et al [28] found a higher incidence of hospital admissions for adult female than for adult male asthmatic patients and that female asthmatic patients experienced longer hospital stays per admission than males.

Degree centrality: Degree centrality of a node in a social network is the total number of links incident to that node. In the context of network analysis, degree of an actor is the count of the number of ties from that actor to other actors. In networks that display the directional flow of actor movement, degree can be assessed for in-degree and out-degree, where ‘in’ represents other actors’ visits to a particular actor and ‘out’ represents that particular actor’s visits to other actors. [29]

Tie Strength: defines the quality of relationship between two actors in a network. According to Granovetter, [22] the strength of relation between two actors can be expressed as a combination of the amount of time and the reciprocal services which characterise the tie between them. In the context of PCCN, for example, the tie strength between doctor and patient could be a combination of time that doctors spend during their visits to patients and how much patients pay to doctors for their visits in return.

Connectedness: Network connectedness or connectedness defines the frequency of communications between two actors. In PCCN, it dictates the frequency of doctors’ visits to a particular patient.

Length of Stay (LOS): defines total number of days that patients stay at hospital during their hospital admissions.

3.2 Research dataset

To explore relations among independent, dependent and moderating variables of the proposed model for PCCN, as illustrated in Figure 3, we used health insurance claim data. This dataset is provided by an Australian non-profit health insurance organisation – The Hospital Contribution Fund (HCF). It includes member claim data from January 2005 to February 2009. In this dataset, there are mainly three different categories of claims lodged by patients, hospitals and doctors: (i) ancillary claim; (ii) medical claim; and (iii) hospital claim. Ancillary claims are auxiliary claims for medical services such as dental, optical, physiotherapy, dietician and pharmaceutical. All claims lodged by specialist physicians except the ancillary type, are medical claims. The claims for the services provided to hospitalised patients in private or public hospitals that are approved by the Australian Department of Health, 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 were about 14.87 million ancillary claims, 8.98 million medical claims and 3.1 million hospital claims that HCF received from 2507 hospitals for the health services provided to its 0.44 million members over the data collection period. As people have hospital admissions for a wide range diseases, in this research we considered claim data only for Total Hip Replacement (THR) patients. Each THR admission had medical claims, hospital claims and a few ancillary claims. The summary of different types of claims for THR patients from our dataset is given in Table 1.

3.3 Exploring data

We measured degree centrality for a patient by counting the total number of doctor-visits to that patient during their hospitalisation period. As each doctor-visit to a patient is responsible for a medical claim to HCF, the total medical...
claims that a patient has during their hospitalisation period is the value for degree variable. The ratio of the expenses for hospital claims and the total hospitalisation cost is the tie strength of a patient with the hospital. To calculate a patient’s connectedness with doctors, we divided the total number of doctor-visits (ie, medical claims) by the number of different doctors who visited that patient during their hospitalisation period. For example, during a hospitalisation period, a patient (say Ms X) has 28 medical claims from four doctors to HCF that cost HCF an amount of $4200. Also, the hospital makes another $5500 claim to HCF for its other medical services to that patient. Therefore, the total expense to HCF for that patient is $10,000 ($4200 + $5500 + $400= $10,000). The degree centrality value is 28. The patient tie strength with hospital is 5.5 (the ratio of $5500 and $10000). The number of visits per doctor (ie, patient connectedness with doctor) is seven (28 divide by four). This is illustrated in Figure 4.

An examination of degree centrality, tie strength and connectedness of PCCN for THR dataset reveals common distributions for all of them, which follow a non-normal curve. Each histogram graph consists of a centralised score having a small tapered skew either to the left or to the right. These distributions are against a line indicating that a non-normal and non-parametric statistical test is required in order to test their correlation with LOS. The Spearman test, which is a standard alternative to the parametric Pearson test, is a non-parametric method for correlation testing to quantify association between two continuous scores. [30]

For this reason, we conducted Spearman tests to examine relations between independent and dependent variables of the coordination performance model for PCCN.

### Table 1: Summary of dataset considered to explore PCCN model

<table>
<thead>
<tr>
<th></th>
<th>TOTAL</th>
<th>THR</th>
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</thead>
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<td>#. Hospital admitted patients</td>
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<td>2352</td>
</tr>
</tbody>
</table>

![Figure 4: Example of the calculation of network attributes for a patient (Ms X)](image-url)
3.4 Findings from Patient-Centric Care Network model

According to the Spearman correlation coefficient values of Table 2, all three independent variables of the coordination performance model of PCCN show positive correlations with the single dependent variable.

3.4.1 Causal effect

There is a positive correlation between degree centrality and patient hospital LOS.

We found a positive correlation (rho = 0.763, p<0.01 at 2-tailed) between degree centrality and LOS. The increased number of doctor-visit to patients made their inpatient stay in hospital longer. Depending on the patients' clinical condition, hospitals may need to invite specialist doctors from outside to visit their patients. As those specialist doctors are very much in demand, patients need to wait for their available time, which in turn extends their LOS. Furthermore, there could be interdependency between doctor-visits to patient. For example, before surgery, surgeons have to wait for all required medical tests to be completed by doctors and other medical staff. For these kinds of interdependency, the dependent doctors (in this case surgeons) have to wait for patient to be visited by the independent doctor and/or medical staff. This kind of interdependency sometimes makes patient LOS higher.

In PCCN, degree centrality for a patient counts not only the presence of links with doctors but also the weights of all such links. The weight for the link between a patient and a doctor indicates the number of times the patient is visited by that doctor. We summed up weights of all links that a patient had with doctors to quantify degree centrality attribute. This finding therefore suggests that patients need to have less doctor-visits during their hospitalisation period in order to make their hospital LOS shorter. At the same time, assurance that patients receive proper treatment from healthcare providers or hospitals is required. Thus, in order to make patients’ LOS shorter, healthcare managers or administrators have to focus on minimising the number of doctor-visits whilst fulfilling patient expectation and providing the right treatment.

There is a positive correlation between tie strength and patient hospital LOS.

We observed a positive correlation between tie strength and LOS (rho = 0.295, p<0.01 at 2-tailed). The more services a patient receives from hospital, the higher the LOS will be for that patient.

The tie strength measure of PCCN reflects the proportion of cost associated with the services provided to patients by healthcare providers or hospitals. We considered hospital claims to measure patients’ tie strength with hospital as they cover all types of services such as primary care, pathological test, medical examinations, accommodation, etc. that patients receive while hospitalised. A positive correlation between tie strength and LOS conveys the message that less cost for services provided by hospitals makes LOS shorter. Alternatively, if the cost for medical claims (ie, for doctor-visits) increases then the percentage of hospital cost (ie, tie strength) will decrease. Healthcare managers or hospital administrators can do it by emphasising the increased number of doctor-visits to patients. However, then the degree centrality value, which affects LOS positively as discussed in the previous findings, will also increase. Another possible way is to encourage doctors to spend more time with patients during their visits, which would eventually increase the total medical cost because the charge for the doctor-visit to a patient depends on its duration. This will increase the cost for medical claims and eventually reduce the percentage of hospital cost (ie, tie strength). Furthermore, longer doctors’ visiting hours will increase patient satisfaction, [31] keep degree centrality value unchanged and decrease patients’ tie strength with hospitals – all of these enable hospitals to manage LOS effectively.

### Table 2: Correlation of coefficient values between independent and dependent variables of PCCN model

<table>
<thead>
<tr>
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<th>LENGTH OF STAY (LOS)</th>
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</thead>
<tbody>
<tr>
<td>Degree</td>
<td>0.753**</td>
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<tr>
<td>Tie Strength (Hospital)</td>
<td>0.295**</td>
</tr>
<tr>
<td>Connectedness</td>
<td>0.663**</td>
</tr>
</tbody>
</table>

Note**: Correlation is significant at the 0.01 level (2-tailed)
There is a positive correlation between connectedness and patient hospital LOS.

We found a positive correlation (rho=0.663, p<0.01 at 2-tailed) between patients’ connectedness with doctors and LOS. The connectedness attribute of PCCN implies the average number of doctor-visits to each patient. So, there are two ways to manage connectedness: (i) by controlling the total number of doctor-visit; and (ii) by controlling the involvement of the total number of doctors to patient episodes of care. The positive correlation between degree centrality and LOS (i.e. the first causal effect) already discusses the way to restrain LOS by controlling the total number of doctor-visits (i.e. the first way). The only option left for the healthcare managers or administrators to manage the connectedness is to control the number of doctor involvements to each patient episode of care. As connectedness correlates positively with LOS, this finding encourages the involvement of more doctors during the episode of patient care in hospital in order to make hospital LOS shorter. However, the chance of medical error in any episode of patient care is high if too many doctors are involved in that episode of treatment. [32] Therefore, if this finding is adopted to reduce hospital LOS, attention has to be given (by healthcare managers or other care administrators) in order to reduce the chance of errors.

### 3.4.2 Moderating effect

To test the effects of moderating variables, we first clustered our dataset based on those variables. Then we compared the correlation coefficient values between the independent and dependent variables of our proposed model for each cluster. The result is given in Table 3.

**Gender Effect:** We clustered THR dataset based on patient sex: male and female. Degree, tie strength and connectedness showed strong positive relations with LOS for both clusters. A further investigation of the correlation coefficient values revealed that the female group showed a stronger positive relation for all combinations between independent variables and LOS than the male group.

**Patient Age:** On the basis of patient age, we clustered the THR dataset in two groups: age group 1 (AG1) and age group 2 (AG2). The average age of all THR patients in our dataset was 58.70 years. All THR patients who were younger than the average age (58.70 years) belonged to AG1 and the rest belonged to AG2. AG1 showed a stronger correlation than AG2 for any combination of independent variables and LOS.

**Provider Type:** All patient admissions were classified as either public or private depending on the type of healthcare service providers. Although in relation to the health service provider type a strong relation was noted for all combinations of independent network variables and LOS, admissions in private hospitals showed stronger correlation than the admissions in public hospitals.

### Discussion and conclusion

In this study, we suggest a social network-based framework to model coordination performance of a group of individuals working in an integrated healthcare environment. Coordination problems can be viewed as the presence of interdependencies among actors within a social network which emerges during the course of attaining a goal or completing a task. We applied SNA and network theory to explore and quantify the position of each actor (or individual) within this network and conceptualised the impact of different network positions of actors on their coordination performance. This proposed framework can be exercised in various settings (eg, inter-departmental collaboration within hospital) of healthcare providers or hospitals to model their coordination performance. SNA measures (eg, degree centrality and closeness centrality) are

<table>
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<tr>
<td>Connectedness</td>
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<td>0.657**</td>
<td>0.698**</td>
<td>0.553**</td>
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</table>

*Note**: Correlation is significant at the 0.01 level (2-tailed)
considered as independent variables; socio-demographic characteristics (eg, age and sex of patient) are considered as moderating variables; and indices representing coordination performance (eg, patient hospital LOS and patient satisfaction) are utilised as dependent variables in this framework.

We successfully applied the proposed framework to model the coordination performance of patient-centric care network (PCCN). For PCCN, we observed that network attributes of degree centrality, tie strength and connectedness had a positive correlation with hospital coordination performance (ie, LOS). We further found that, for PCCN, socio-demographic characteristics of patient age, patient sex and provider type moderate the relationship between any pair of independent and dependent variables. By combining these two findings, healthcare managers can identify positive attributes of PCCN, which could lead them in designing effective healthcare or hospital settings. Not only that, the current setting of any PCCN can be reviewed and judged against these two findings in order to observe its present state of coordination performance.

The selection of dependent, independent and moderating variables in exploring PCCN using the proposed coordination modeling framework was guided by the research dataset used in this study. We utilised secondary data sources (ie, electronic claim details of the health insurance organisation) in exploring PCCN. We considered only three network measures as independent variables; however, those studies consider, in addition to LOS, other possible performance measures (eg, readmission rate, patient satisfaction and mortality). [15,33] Similarly, patients’ previous medical history could be another moderating variable, which has been used by researchers, [36] to explore healthcare performance. On the other hand, we did not establish either the minimum or maximum threshold for which network attributes no longer provide coordination performance although we showed that attributes of PCCN have an impact on coordination performance.

**Competing Interests**
The authors declare that they have no competing interests.

**References**