#18

THE DYNAMIC NATURE OF CAREGIVER COMMUNICATION NETWORKS AND SPATIALISED WORK PROCESSES IN HOSPITAL WARDS

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ABSTRACT

This paper presents an empirical study of four hospital wards in two UK hospitals. Of interest are caregiver communication networks and behaviours because they form an important part of care provision. Space syntax research argues that the spatial configuration of buildings has an effect on social behaviours. However, only few notable studies investigate how inpatient wards influence work processes and relationships amongst caregivers. The dynamic nature of this work environment is particularly challenging to observe. Therefore, this study focuses on spatial layouts and dynamically evolving communication networks and behaviours adopting a set of complimentary methods to disentangle the complex and dynamic social processes in hospital wards.

The two case studies are situated in London and were specifically selected to contrast in their setup and spatial organisation. Two corresponding inpatient departments in each hospital were chosen for a comparison – the intensive care unit and one medical ward. Space syntax was used alongside a staff survey including social network analysis to assess communication networks amongst caregivers. The survey was carried out for four consecutive days and asked about communication partners on each particular day to capture snapshots of everyday communication that could explain the dynamics of social networks. Sociometric sensors developed at MIT were run for eight consecutive days and provided information about frequency and duration of conversations. The dynamic nature of the workflow was captured by shadowing caregivers and recording digitally type and durations of sequential activities and locations.

The study offers several contributions by bringing together spatial analysis, observational data, self-reported surveys and sensor data. Results indicate that the structure of communication networks of doctors and nurses became less hierarchical to keep the network stable when a key role was missing. It was also shown that distance influence the frequency and duration of conversations in the intensive care unit assuming that caregivers are fixed to their assigned beds. However, for the general nursing ward, a different methodology to model distance is required as one caregiver takes care of several physically dispersed patients. Finally, it was shown that

nurses spent a great proportion of their time in various activities in different locations pointing towards the dynamic nature of the workplace. The outcome of this study generates insights into everyday life in hospital wards and how spatial practices play out.

KEYWORDS

Space syntax, social network analysis, hospital ward layout, communication networks, sociometric sensors

1. INTRODUCTION: THE DYNAMIC NATURE OF HOSPITAL ENVIRONMENTS

Hospitals operate in a fast-paced 24/7 service economy. By arranging various user groups through elaborate routines and work patterns and a flow of materials and people into large spatial configurations, they form complex, diverse and multi-layered environments. Complexity could be argued to arise from three main factors: process dynamics, interface dynamics and organisational dynamics.

Firstly, the way processes play out in the physical environment of hospitals is dynamic as they accommodate a variety of building usage patterns. Sailer (2015) argued that buildings are dynamic settings that accommodate a range of different uses for example a hospital is not just a place for curing the ill, but also a workplace for clinicians. The author showed how the nature of usage patterns in libraries is dynamic by taking into account the diversity of user groups as well as the temporal unfolding of behaviours. Similarly, hospitals are dynamic settings because they accommodate a multitude of functions as well as a variety of user groups – consultants, doctors, students, matrons, nurses, nursing assistants, porters, cleaners, pharmacist, physiotherapists, patients and visitors whose day-to-day tasks and activities vary across days. To add to this complexity, there are several different levels of nurses as well as doctors (Figure 1) resulting in different responsibilities and usage patterns. For example the matron or the nurse in charge of a ward has a managerial role while the nurse educator is responsible for the continuous professional education of nurses. None of these roles takes care of patients.

Figure 1 - NHS nurse and staff uniforms

Another investigation of work process and routines in a university hospital was conducted by Koch and Steen (2012a, 2012b). The authors used the concept of spatial practice to 'de-compose' work programmes. The concept represents the interaction between spatial configuration, organisational configuration and configuration of work processes and routes. The authors chose cases with similar general workflow principles and argued that similar tasks and roles were realised in space differently and that similar tasks and roles were also realised in time differently. These differences add another layer of complexity to the space usage patterns in hospital wards.

Secondly, two main interfaces exist between visitors and inhabitants of a hospital: caregiver-patient and caregiver-caregiver interface (Hanson and Hillier, 1984). However, as the inhabitants are not just caregivers but various different types and levels of caregivers, the resulting interfaces are much more complex and dependent on the daily regimes of the various user groups. How and where inhabitants and visitors interact depends very much on the type of the user group. For example, a haematology nurse may need to take care of a patient in pulmonology because the patient requires their expertise. This would result in deviation of the nurse from their usual daily regimes and interactions with the members of staff in the new ward.

Thirdly, hospitals are dynamic organisations since the workload of caregivers is organised around multiple shifts that involve a considerable flux of personnel. This means that the composition of professionals may vary greatly from one day to another, resulting in unstable teams. To study the dynamic nature of work environments in courts, Lazega et al. (2009) coined the term 'relational turnover' to describe changes in the network structure of judges regardless of the turnover of its individual members. The idea was that a role in the network remains stable, but the person filling the role changes. It was found that the hierarchy of status remained relatively stable regardless of members' turnover while role relationship and division of work showed that the relational turnover was high.

Valentine and Edmondson (2015) studied a similar process but in hospitals. The researchers investigated the redesign of an emergency department – both organisationally and physically, and showed how the work dynamics can be controlled to improve patient throughput time. Prior to the redesign, individuals coordinated work in a role-based structure where interactions occurred in unstructured groupings. After the redesign, the ED implemented new organisational structures that bounded small sets of roles and gave them shared responsibility for a group of patients. The authors labelled these as team scaffolds because they acted as a stable structure that helped extremely fluid groups to act like a team. The hospital ED also implemented a spatial redesign dividing the large unit into four pods. A pod was a physical location with dedicated computers, supplies and patient beds acting as a stable structure that persisted over time but the individuals staffing each pod changed constantly.

Despite its dynamic workplace environment, it could be argued that hospitals still operate similarly to buildings where the work force is less mobile e.g. offices. For example, in a seminal study Allen (1975) investigated communication patterns amongst engineers and found that the longer the distance between their desks the less like they were to talk to each other. This is obviously a static way of looking at the workplace, however it is still valid in office buildings despite workforces becoming more flexible (Sailer 2010, Catalini 2016).

Therefore, the interest of this paper lies in measuring and spatialising the dynamic nature of hospital wards, drawing on both quantitative and qualitative empirical data sets collected in four hospital wards in 2016. In detail, the research questions are:

1. With regards to organisational dynamics, does the structure of the communication network of doctors and nurses change when a key role is missing?
2. Does the distance-communication frequency relationship often found in workplaces also hold in hospitals despite a more mobile work pattern?

The aim of the paper is to generate insights into the everyday life of hospitals and to more accurately describe and depict the role of the layout in shaping communication patterns and care processes.

The paper continues with a review of the space syntax literature in hospital wards and discusses how researchers have investigated the relationship between the spatial layout and caregiver processes and communications. Next, the four case studies and methodology used are described in detail. Then, we present the results from the analysis of how distance influences communication in hospitals. Conclusions, limitations and future work are presented in the final sections of the paper.

2. THE SPATIALISATION OF CAREGIVER WORK ACTIVITIES AND COMMUNICATION

The application of space syntax in hospital environments is relatively new, however a growing number of studies have looked at how the configurational properties of a hospital affect work processes and communication networks among caregivers.

In a study conducted in an intensive care unit, Lu, Peponis and Zimring (2009) investigated how visibility affected providers' activities and communication. They found that nurses and doctors were tuned to different features of the environment. Doctors' patterns correlated better with generic visibility, which is the standard analysis of visual field calculated from all visible points to all other points in space. On the other hand, nurses' activities were tuned to a new spatial measure developed by the researchers and called 'targeted visibility'. The measure was calculated as visibility directed towards a number of pre-selected foci of attention that are visible e.g. patient beds.

Sailer et al. (2013) conducted studies in outpatient clinics in two hospitals using social network analysis and space syntax. They found that the distance between clinics in one of the hospitals measured in axial steps influenced the communication intensity between caregivers across clinics. The relation was not linear but logarithmic meaning that in close proximity small increases in distance made a bigger difference than for larger distances. However, no relationships between communication intensity and distance across clinics in the second hospital were found.

Trzpuc and Martin (2010) explored how visibility and accessibility in three medical-surgical units influenced nurses' communication and subsequently perceived social support that helped to protect staff from high stress levels and increase job satisfaction. Yet nurses' perception of visibility and accessibility did not consistently match anticipation from the floor plan analysis. The authors concluded that there was a gap in our knowledge of how the nursing units affected nurses' behaviour.

The above studies either found no correlations between various user categories and different space syntax metrics pointing towards what Trzpuc and Martin expressed as a concern: our understanding of how the hospital layout affects caregiver behaviours is rather limited. To study this gap in knowledge, this research aims to explore how dynamically evolving communication networks and work activities of caregivers can be measured and spatialised.

Three different space syntax measures were selected for the present study – metric, visual and angular distances. Metric distance was used because past research showed that the longer the distances between people the less likely they were to communicate with each other (Allen 1975, Sailer 2010, Catalini 2016). Visual distance was chosen because studies indicated that the visibility of a ward layout was highly correlated with density of interaction of doctors (Lu et al, 2009). Finally, angular distance was selected because it has been proved that people tend to prefer straight routes (Dalton 2003).

Hendrich et al. (2009) studied nursing units and based on their data described two overall strategies of nurse mobility patterns affected by the spatial qualities of nurse assignments: fewer, longer visits versus more frequent, shorter visits. This led to the following hypothesis:

H1: The longer the metric (H1a), visual (H1b) and angular (H1c) distance between HCW (healthcare workers), the less likely they are to communicate frequently and the longer the duration of their conversations.

3. CASE STUDIES

This paper draws on data collected in four inpatient wards in two different hospitals. Both institutions belong to the same NHS Trust and are situated in central London. Hospital A was purpose-built and first opened in 2005. Hospital B occupies a building from 1885 and was expanded in several stages hence it consists of a few interconnected buildings.

The intensive care unit (ICU) and one medical ward in each hospital were selected for the study. Table 1 provides an overview of the selected cases. The layout typology of the wards in Hospital A is called 'racetrack' (Thompson and Goldin, 1975) where the core of the building, that contains lifts and staircases, is located in the middle of the floor plate and the main corridor runs around it. All patient rooms and bays are situated along the perimeter of the building to maximise the amount of daylight for patients. The layout of the wards in Hospital B has a 'corridor' structure (ibid). The main corridor runs in the middle of the ward and all patient and staff facilities are situated on both sides. The two wards in Hospital A are 1/3 bigger in terms of bed numbers and have more side rooms than their corresponding units in Hospital B.

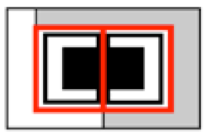
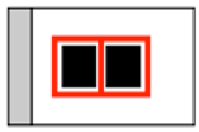
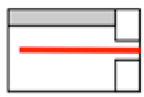
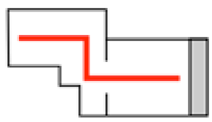
CASE STUDY	FLOOR SIZE	# BEDS	OPEN BAYS / SIDE ROOMS	WARD TYPOLOGY	LAYOUT DIAGRAM
Hospital A Nursing ward	1420 m^2	43	21 / 22	racetrack	
Hospital A ICU	1525 m^2	32	21 / 11	racetrack	
Hospital B Nursing ward	928 m^2	28	24 / 4	corridor	
Hospital B ICU	1380 m^2	20	17 / 3	corridor	

Table 1 - Overview of selected casa studies:

Legend: —— main corridor; ■ building core; ■ patient side rooms

4. METHODOLOGY

This paper combines the syntactical studies of the four wards with data collected from observations, social network analysis surveys and wearable devices. Visibility Graph Analysis (VGA) was constructed on eye level (Turner, Doxa, O'Sullivan & Penn, 2001) in Depthmap X (Varoudis, 2012) and metric, visual and angular distances from any patient bed and nursing station to any other bed and station were then calculated selecting the VGA node that coincided with the middle of the bed or the station.

A staff survey including social network analysis was conducted to assess communication networks amongst HCW. The survey was carried out for four consecutive days and asked for communication partners on each particular day to capture snapshots of everyday communication that could explain the dynamics of social networks. In this paper we used survey data from the nursing ward of Hospital A where the average number of survey participants per day was 32 with daily response rates between 62% and 91%. Communication networks on the exchange of patient-related information were constructed from the data and analysed with UCINET (Borgatti, Everett, and Freeman 2002). Betweenness centrality of individuals as well as the average degree of the networks were calculated. Betweenness shows who controls the flow of information in a network. It is similar to choice in space syntax and is calculated by summing the number of all shortest paths from every node in the system to any other node that passes through the node of interest divided by the total number of shortest paths in the network. The average degree is similar to connectivity in space syntax and shows the average number of communication partners in the network. For instance, an average degree of 5 means that all caregivers spoke to 5 other caregivers on average.

Sociometric badges developed at MIT (Olguin, 2007) were employed to provide additional information about communication behaviours. The devices were used for eight consecutive days with an average number of participants of 15-24. Volunteers were asked to wear the badges around their necks throughout the duration of their shifts. The devices contain Bluetooth and infrared sensors as well as an accelerometer that provided information about the duration and frequency of communication between participants and their body movement and posture during conversations. Data were analysed statistically and visualised with STATA 14 software (StataCorp. 2015).

Caregivers were shadowed during their daily tasks and routines to capture the dynamic nature of the workflow. The observer followed the HCW and recorded on a digital device where they were, what they did there and whom they spoke with selecting from a predefined list of activities and locations. The data provided information about sequence and duration of activities and how much time caregivers spent in certain locations. A total number of 64 caregivers were observed for an average of 45 minutes and different roles were selected including participants from medical, nursing and ancillary staff.

5. ANALYSIS AND RESULTS

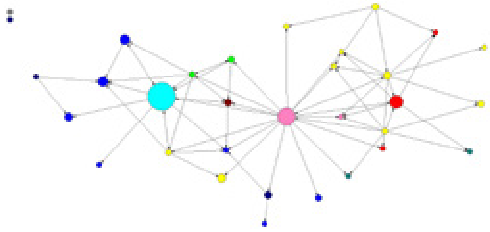
5.1 ORGANISATIONAL DYNAMICS

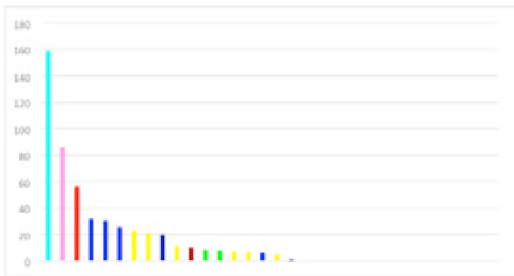
Initially, a network survey over 4 days had to be conducted to understand the communication network of caregivers. However, it was announced that the junior doctors would go on strike a day after the survey was planned to begin. This was a rare opportunity for a natural experiment to investigate the 'relational turnover' (Lazega et al, 2009) of a network when the people fulfilling the roles remained the same but one key role was missing. No junior doctors worked on the strike day and more consultants (senior doctors) were present in the ward to compensate. The survey included the day before the strike when caregivers were preparing for the big day, the strike day, the day after the strike and one ordinary day during the following week. Figure 2 shows the caregiver communication networks for the four different days on the left and the distribution of betweenness centrality on the right.

On the day before the strike the most central figures in the networks were the nurse in charge, the ward administrator and one of the senior doctors. On the day of the strike, the general nurses and the pharmacist were the ones who stepped in and helped the nurse in charge with patient care (Figure 2). The betweenness centrality of the main actors on days 1, 3 and 4 was much higher than the ones on the strike day: for example, the nurse in charge, who is a main actor on days 1, 2 and 4, has a betweenness of 105 on strike day and 158 and 174 on the other days. The standard deviation of betweenness is also lower on the strike day meaning that the data is less dispersed and the values are more equal and close to each other. This shows that the distribution of importance was much more equalised on strike day, thus less hierarchical than on the other days. Average degree also varied across days (Figure 2). Average degree increased from 5.13 to 5.72 on a strike day, reached 6.46 on the day after the strike and dropped down to 4.75 during an ordinary day. This shows how on the day after the strike there was a lot more information to be exchanged resulting in a higher number of communication partners on that day.

In summary, on the day of the strike, the general nurses and the pharmacist were the ones who took control over patient care. While in the case of the court judges (Lazega et al, 2009), the hierarchy of status remained the same regardless of members' turnover, this study found that when a key role was missing, the distribution of importance was less hierarchical which kept the network stable and enabled caregivers to cope with the critical situation. The day after the strike was busier in terms of communication as the junior doctors had to catch up with information.

Day 1: Prepping for the strike

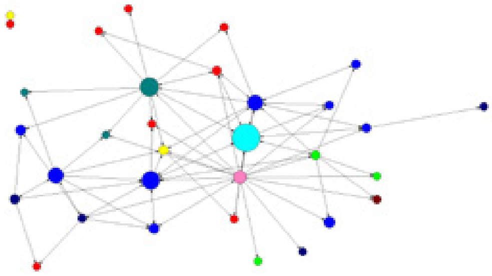


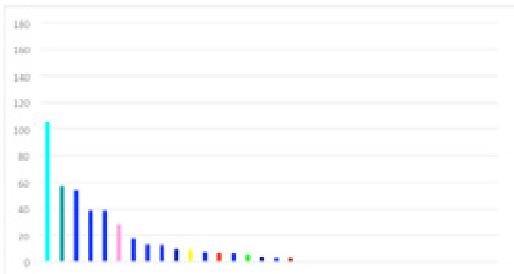


Response rate: 76%
Ave degree 5.13

SD Betweenness 31.55

Day 2: Strike day

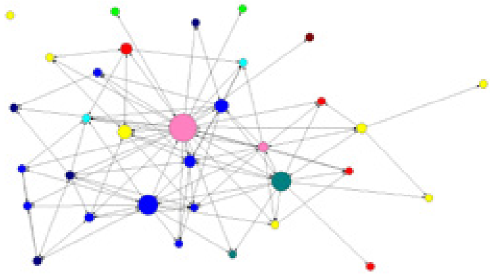


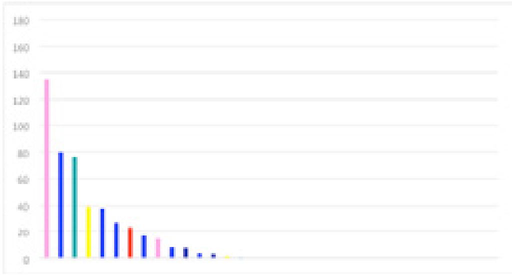


Response rate: 78%
Ave degree 5.72

SD Betweenness 22.72

Day 3: After the strike

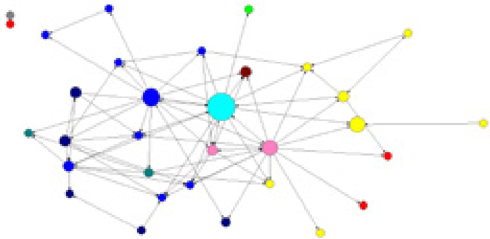


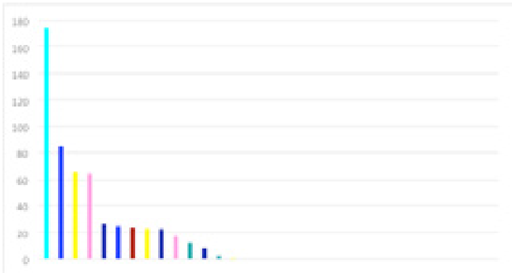


Response rate: 91%
Ave degree 6.46

SD Betweenness 29.33

Day 4: Ordinary day





Response rate: 62%
Ave degree 4.75

SD Betweenness 35.37

Node size: Betweenness centrality

Link: Discuss patient care more than 2 times per day

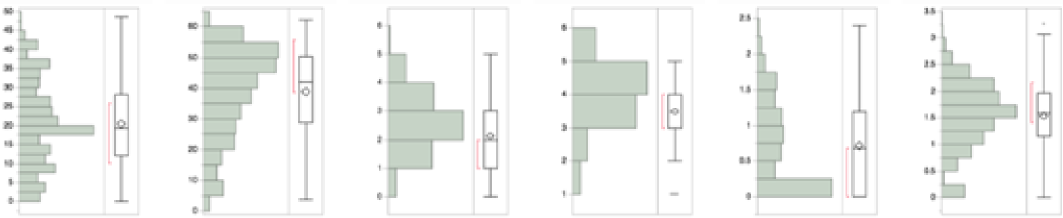
Figure 2 - Network structures of the four days of the network survey (left) and corresponding distribution of betweenness centrality per person (right)

5.2 SPATIAL ANALYSIS

This section describes the layouts of the two intensive care units in terms of metric, visual and angular distances between beds and nursing stations.

Basic statistical information and distribution of the three types of distances for each hospital are presented in Table 2. The maximum distance between beds in the racetrack layout is 62.3m, which is 13.8m longer than the maximum distance of 48.5m in the corridor layout. The mean value of the former is also higher – 34.1m compared to 20.45m in the latter, and the distribution of the data is shifted towards the higher values of metric distance indicating that there is a higher count of longer distances between beds in the racetrack layout than the corridor layout. Similarly, the racetrack layout also has longer distances in terms of visual distance with mean values of 3.5 compared to 2.1 for the corridor layout. However, both hospitals are equally deep – it takes a maximum of five visual steps to reach any space. In terms of angular distance, the distribution of the data shows that the corridor layout has more distances between beds with angular changes closer to 0. This is a result of the 85% of the beds in hospital B being placed in two adjacent open spaces (beds in the same space have an angular distance of 0) while 66% of the beds in hospital A are placed across 4 different open bays and the rest are in side rooms.

In summary, the corridor layout has overall shorter distances between caregivers in terms of metric, visual and angular distance than the racetrack layout.



	HB (corridor)	HA (racetrack)	HB (corridor)	HA (racetrack)	HB (corridor)	HA (racetrack)
	Metric DIST		Visual DIST		Angular DIST	
Mean	20.45	34.10	2.13	3.26	0.71	1.46
Max	48.5	62.3	5	5	2.4	3.26
SD	11.34	14.69	1.04	0.97	0.63	0.66

Table 2 - Distribution of metric, visual and angular distance and basic statistical information

5.3 INTERFACE DYNAMICS

This section tests the hypotheses H1a-c that distances affect communication. For this purpose, distances between caregivers were measured in a similar way as they would be in an office. General nurses were assigned to the bed of the patient they were taking care of. Junior and senior doctors were assigned to the nursing station closest to the patients they were responsible for as this was their workstation. The distances between all nursing stations and patient beds were calculated and assigned to pairs of caregivers. Assigning caregivers to locations was only done for the intensive care units where the nurse to patient ratio is usually 1:1 meaning that the task of assigning a caregiver to a bed is feasible. On the other hand the nurse to patient ratio in the general nursing ward is 1:4 or 1:5 which makes the task impossible and raises methodological questions not discussed in this paper.

A statistical model was used to test the relationship between communication and distance. Frequency and duration of conversations, extracted from the sociometric badges, were used as dependent variables. The three types of distances – metric, visual and angular, were used as independent variables. Gender, role and experience of caregivers served as control variables. Participants were split into male and female for gender, doctor and nurses for role and junior and senior for experience.

5.3.1 GENERAL DESCRIPTION OF THE DATA

A total number of 287 unique participants took part in the study with the badges of which 175 were in hospital A and 112 were in hospital B (Table 3). In terms of gender split, there were more female than male participants in both hospitals – 59% (HA) and 67%(HB). As for the split of roles, nurses represented a greater proportion of the study population for both cases – 64% (HA) and 88%(HB). Finally, 57% and 55% of the participants in hospital A and B respectively were junior level staff.

The distribution of frequency for both layouts is exponential where 55-60% of the communication events consisted of 1-5 conversations per day and then the number of events dropped dramatically (Table 4). The data for Hospital B is more distributed that the one for Hospital A with maximum frequency of conversations per day = 131 and SD = 22.5 compared to maximum frequency = 75 and SD = 11.7 (HA). This meant that caregivers in the corridor layout had a lot more frequent conversations than caregivers in the racetrack layout.

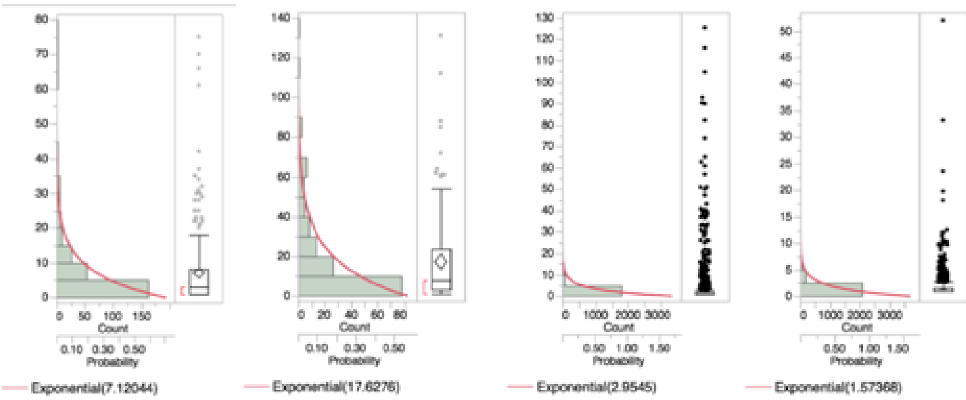
The distribution of duration for both case studies was exponential too with 90% probability to have a conversation for less than 5 minutes long and 80% probability to have a conversation that is less than a minute long. The highest duration of conversations was 125.4 minutes long in hospital A and only 52 minutes in hospital B.

In summary, a greater proportion of the participants consisted of female participants, nurses and junior level staff. There were a lot more frequent and shorter conversations in the corridor layout while caregivers in the racetrack layout communicated less but had longer conversations.

	Total	Gender		Role		Seniority	
	All participants	Male	Female	Doctor	Nurse	Junior	Senior
HA (racetrack)	175	71	104	42*	112*	99*	54*
HB (corridor)	112	37	75	13	99	62	50
Total	287	108	179	55	211	161	104
		287		266		265	

*Role and Seniority information was unavailable for 21 and 22 participants respectively out of the total 175 for HA

Table 3 - General information for participants in hospital A and hospital B



	Frequency		Duration	
	HA (racetrack)	HB (corridor)	HA (racetrack)	HB (corridor)
Max	75	131	125	52
Mean	7.12	17.63	2.3	1.6
SD	10.56	22.55	5.3	1.8
Variance	111.64	508.47	29.0	3.35
N	274	145	1582	2461

Table 4 - General statistics for frequency and duration of conversations in hospital A and hospital B

5.3.2 RESULTS FROM THE STATISTICAL ANALYSIS

The conditional variance of the two dependent variables – frequency and duration, exceeds their conditional mean for both cases, which means that the data is over dispersed (Table 4). Therefore, negative binomial regression is used for the analysis as it is a statistical model that accounts for over dispersion. Results from the regression analysis for frequency for the two hospitals are presented in Table 5a and results for duration in Table 5b. Three different models for each of the dependent variables were tested including each of the independent variables separately and all of the control variables. To compare the models within each case study the maximum log likelihood was used which examines the fit of different coefficients. Because one wants to maximise the log likelihood, the higher the value the better. Alongside the coefficients, the IRR[1] (incidence rate ratio) is calculated only for statistically significant results, which is then used to present the findings as percentages. Predictive margins were computed from predictions from each model for different values of the covariates. They indicated how frequency and duration depend on the three types of distances in the two hospitals and the graphs on Figure 3 shows the shape of the effect.

All three distances for both hospitals produced highly significant results (p=0.000) and influenced frequency negatively meaning that with increasing distance between caregivers the frequency of their conversations decreased (Table 5a and Figure 3). The maximum log likelihood results were produced by the model containing visual distance for hospital A and metric distance for hospital B. This meant that from the three different types of measures, visual distance was the best predictor for the racetrack layout and metric distance for the corridor layout. Results for hospital A showed that if everything else was kept stable, with every one metre increase in distance, there was a 3% decrease in communication frequency; with every one increase of visual step depth there were 39% fewer conversations; and with every one increase of angular step depth there were 45% fewer conversations. The results for hospital B are similar and show that if everything else was kept stable, with every one metre increase in distance, communication frequency dropped by 6%; with every one increase of visual step depth there were 50% fewer conversations and with every one increase of angular step depth there were 45% fewer conversations. It can be concluded that the corridor layout had a slightly bigger impact on frequency of communication than the racetrack one.

Of the control variables, only seniority of caregivers in hospital A gave highly significant results and thus had an effect on frequency of conversations. It was found that junior doctors were more likely to communicate with other junior doctors while senior doctors were more likely to speak more often to junior doctors. None of the control variables in hospital B produced highly significant results.

Similarly, all three distances for both hospitals produced highly significant results (p=0.000) and influenced duration (Table 5b). However, differences were found between the two layouts. While distances in the racetrack layout influenced duration positively meaning that with increase of distance, the duration of conversations increased, on the other hand, distances in the corridor layout influenced duration negatively meaning that with increase of distance between caregivers the duration of their conversations decreased (Figure 3).

This phenomenon will be explored in future studies as it could be equally a result of the management of the hospital, the daily routines and regimes of caregivers or the spatial layout.

The maximum log likelihood results were produced by the model containing metric distance for both layouts meaning that physical distance measured in metres was the best predictor for duration of conversations. Results for hospital A showed that if everything else was kept stable, with every one meter increase in distance, there was a 1% increase in duration; with every one increase of visual step depth there was a 16% increase in duration; and with every one increase of angular step depth there was a 13% increase in duration. The results for hospital B showed that if everything else was kept stable, with every one meter increase in distance, the duration of conversations decreased by 2%; with every one increase of visual step depth there was a 22% decrease in duration and with every one increase of angular step depth there was a

1 IRR is the ratio of the incident rate for two values of x one unit apart – easier to calculate percentages.

17% decrease in duration. Again, the corridor layout had a slightly bigger impact on duration of conversations than the racetrack one.

Gender and role of caregivers influenced the duration of conversations in hospital A. Results showed that females were more likely to have longer conversations with other females than with males while males were more likely to have shorter conversations with other males than with females. Nurses were more likely to have longer conversations with doctors than with other nurses while doctors were more likely to have longer conversations amongst themselves than nurses would do. Only the role of caregivers in hospital B had an effect on the duration of interactions. There were no recorded conversations amongst doctors. Results showed that similarly to hospital A, there was a higher probability of a nurse to have a longer conversation with a doctor than with another nurse.

The conclusions from the analysis in this section are used to reflect on the stated hypotheses and are summarised below. With increase of distance in the racetrack layout, communication events decrease and the duration of conversations increases meaning that caregivers have shorter and more frequent conversations in close proximity and longer but less frequent conversations when distances increase. On the other hand, with increase of distance in the corridor layout, the communication events decrease but also the duration of conversations i.e. caregivers have more frequent and longer conversations in close proximity.

HYPOTHESIS	Racetrack	Corridor
H1a: The longer the metric distance between clinicians		
A) the less likely they are to communicate frequently	✔	✔
B) the longer the duration of their conversations	✔	
H1b: The longer the visual distance between clinicians		
A) the less likely they are to communicate frequently	✔	✔
B) the longer the duration of their conversations	✔	
H1c: The longer the angular distance between clinicians		
A) the less likely they are to communicate frequently	✔	✔
B) the longer the duration of their conversations	✔	

	HA (racetrack)			HB (corridor)		
	coeff.	p. value	IRR	coeff.	p. value	IRR
Metric DIST	0.0141	0.000	1.01	-0.021	0.000	0.98
f-f	-0.168	0.016	0.85	0.055	0.147	-
m-m	1.008	0.000	2.74	0.055	0.477	-
n-d	-0.159	0.018	0.85	0.259	0.000	1.30
d-d	-0.919	0.000	0.40		*omitted*	
j-j	-0.124	0.224	-	-0.054	0.135	-
s-s	0.003	0.964	-	0.047	0.536	-
Log likelihood		-3116.80			-3656.36	
Visual DIST	0.151	0.000	1.16	-0.246	0.000	0.78
f-f	-0.168	0.016	0.85	0.006	0.871	-
m-m	0.876	0.000	2.40	0.030	0.664	-
n-d	-0.192	0.005	0.83	0.241	0.000	1.27
d-d	-0.959	0.000	0.38		*omitted*	
j-j	-0.055	0.580	-	-0.052	0.153	-
s-s	0.070	0.333	-	0.048	0.527	-
Log likelihood		-3123.19			-3656.38	
Angular DIST	0.123	0.005	1.13	-0.184	0.000	0.83
f-f	-0.151	0.030	0.86	0.071	0.063	-
m-m	0.861	0.000	2.37	0.006	0.933	-
n-d	-0.186	0.007	0.83	0.235	0.000	1.26
d-d	-0.956	0.000	0.38		*Omitted*	
j-j	-0.012	0.901	-	-0.027	0.456	-
s-s	0.114	0.112	-	-0.062	0.411	-
Log likelihood		-3131.55			-3688.92	

Table 5a - Results of negative binomial regression for duration for hospital A and hospital B

	coeff.	p. value	IRR	coeff.	p. value	IRR
Metric DIST	-0.034	0.000	0.97	-0.065	0.000	0.94
f-f	0.208	0.148	-	-0.048	0.792	-
m-m	0.132	0.593	-	-0.435	0.134	-
n-d	-0.077	0.591	-	0.166	0.451	-
d-d	0.647	0.090	-		*omitted*	
j-j	-0.334	0.043	0.72	0.230	0.227	-
s-s	0.463	0.004	1.59	-0.263	0.323	-
Log likelihood		-792.34			-543.64	
Visual DIST	-0.494	0.000	0.61	-0.691	0.000	0.50
f-f	0.217	0.129	-	-0.149	0.424	-
m-m	0.234	0.339	-	-0.519	0.081	-
n-d	0.100	0.470	-	0.125	0.580	-
d-d	0.961	0.010	2.62		*omitted*	
j-j	-0.331	0.042	0.72	0.098	0.613	-
s-s	0.367	0.018	1.46	-0.327	0.228	-
Log likelihood		-789.51			-547.04	
Angular DIST	-0.596	0.000	0.55	-0.607	0.001	0.54
f-f	0.195	0.180	-	-0.072	0.709	-
m-m	0.298	0.237	-	-0.575	0.066	-
n-d	0.180	0.201	-	0.161	0.049	-
d-d	1.005	0.008	2.73		*omitted*	
j-j	-0.384	0.019	0.68	0.270	0.184	-
s-s	0.318	0.047	1.37	-0.413	0.146	-
Log likelihood		-795.88			-554.97	

Table 5b - Results of negative binomial regression for frequency for hospital A and hospital B

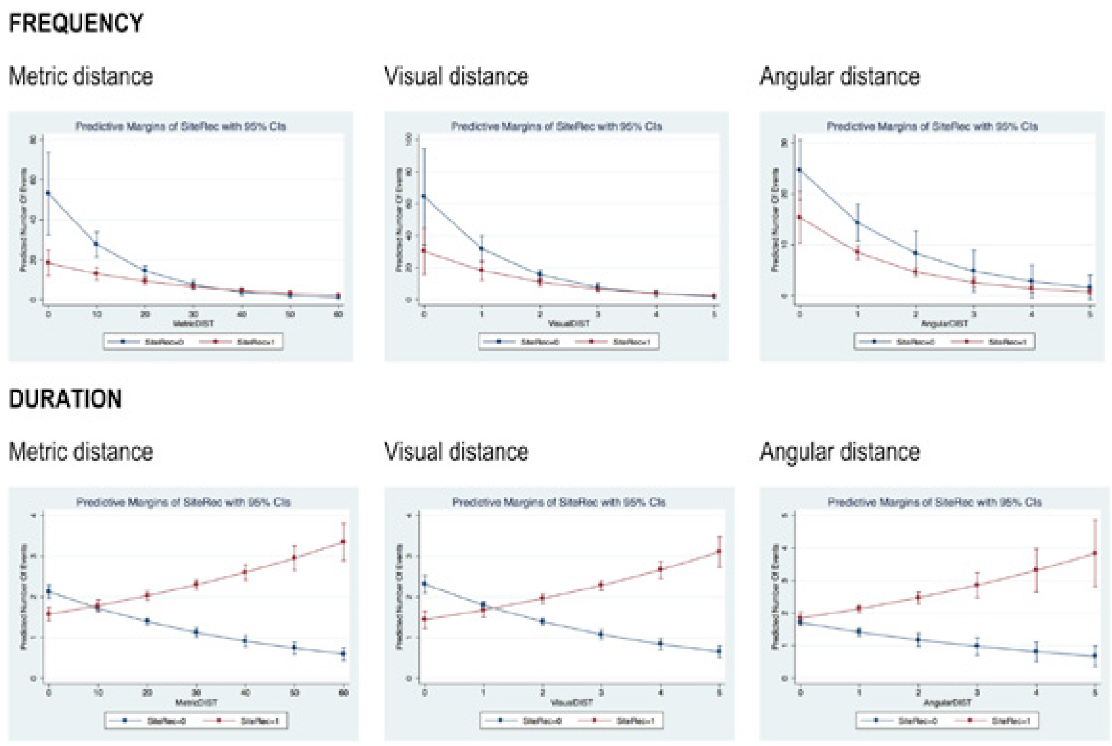


Figure 3 - Shape of the effect of distance on frequency and duration of communication – Hospital A in red and Hospital B in blue

5.4 PROCESS DYNAMICS

To investigate the dynamic nature of work process in hospitals further, results from the observations in the four units are presented in Figure 4. The pie charts show the amount of time nurses spent in various activities. For the two intensive care units, nurses spent 23% and 19% of their time in pure patient care in hospital A and hospital B respectively. For the general nursing wards, the percentages are 23% and 14%. These results show that nurses spent a great proportion of their time in other activities, which further emphasises the problem of assigning caregivers to fixed locations.

The presented analysis where the ward environment was considered as static and caregivers were assigned to beds and nursing stations was done in the intensive care units of the two case studies where providers took care of one patient or group of patients. It was impossible for the study to be reproduced in the general nursing wards were one care provider was responsible for several usually spatially dispersed patients. This means new methods need to be developed in further work.

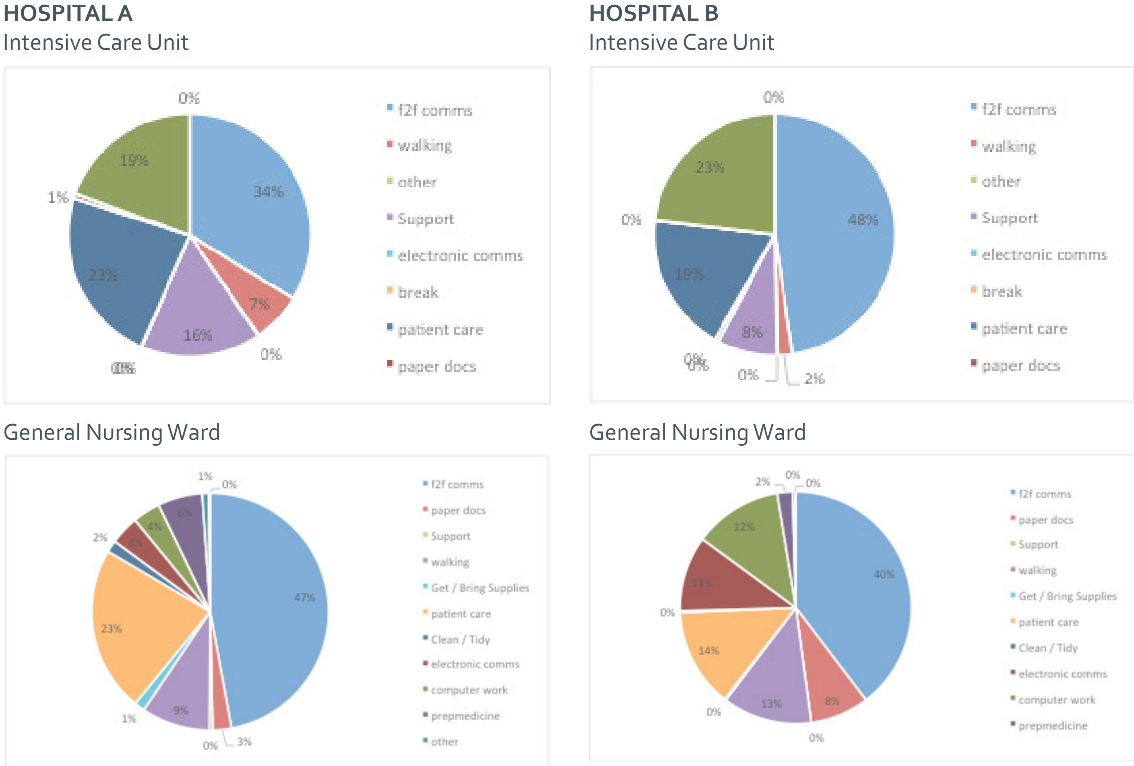


Figure 4 - Time spent by general nurses in different activities

6. CONCLUSIONS

This paper brings together spatial analysis, observational data, self-reported surveys and sensor data collected in four inpatient wards. Of interest was how organisational, interface and process dynamics influenced communication and work processes of caregivers. On an organisational level, it was shown that when a key professional role – junior doctors – was missing the resulting communication network was less hierarchical which was important to keep the network stable and cope with the critical situation. Instead, the nurse in charge was supported by the other nurses and the pharmacist, which were usually less central to the network. It was also shown that the distance-communication frequency relationship that was often found in workplaces was also present in hospitals. Two different ward layouts were investigated – racetrack and corridor, and it was shown that with increase of distance in the racetrack layout, communication events decreased and the duration of conversations increased while with increase of distance in the corridor layout, communication events decreased but also the duration of conversations. These inconsistences could be a result of either differences in management, regimes and processes or the spatial layout and future studies will investigate this further. As for process dynamics, results showed that contrary to common thinking that nurses spend most of their time with patients, they actually spent a great proportion of their time in various other activities in different locations.

Although very rich data was gathered for the present study some limitations should be noted. First, inaccuracies may have occurred since observations may suffer from biases introduced by the human observer. Also, caregivers were sampled and not everyone was followed. Second, the self-reported survey on communication may have suffered from recall bias since the survey was conducted at the end of the shift when caregivers were already tired. Third, more cases could be analysed to test and extend the argument further. Finally, with regards to the sociometric badges 1) they were not enough to cover all caregivers in the ICU of Hospital A while the ICU in Hospital B was smaller and almost every care provider wore a badge; 2) some of the caregivers did not wear the badge around their neck because the device was either too heavy for them or they felt that they looked weird to walk around the ward with a blinking device. Those caregivers placed the badge either in their front or back pocket, which could have affected the quality of the data; 3) some of the devices broke during the study which was only discovered at the end of the data collection period causing missing data from key actors; 4) it is not always clear what a single conversation event is for the device and when a conversation starts and ends.

In future work, the authors will look at other possible ways to model space in dynamic hospital wards. One way will be to take the actual work paths of caregivers from the observational data and look at the overlapping paths between providers on a dyadic level (Kabo, 2013). It will be tested whether the integration of the overlapped paths is a better predictor for duration and frequency of communication. It could be hypothesized that the higher the integration of the overlapped paths, the shorter and more frequent the conversations are. Additional data from a third case study will be added exploring the ward layout typologies further. Differences between badge data and reported network data will be also explored. The gathered data will be cross-referenced with quality of care metrics to better understand the implications of the ward layout on healthcare.

In conclusion, the main contribution of this paper is the idea of a hospital ward as a layered, dynamic and changing environment organisationally, procedurally and in terms of interfaces rather than as a static and definite entity that works in one particular way.

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