A Modeling Approach for Estimating the Impact of Spatial Configuration on Nurses' Movement

Yeonsook Heo
Georgia Institute of Technology, College of Architecture, Atlanta, United States
yeonsook.heo@gmail.com

Ruchi Choudhary
University of Cambridge, Engineering Department, Cambridge, United Kingdom
r.choudhary@eng.cam.ac.uk

Sonit Bafna
Georgia Institute of Technology, College of Architecture, Atlanta, United States
Sonit.Bafna@coa.gatech.edu

Ann Hendrich
Ascension Health, Clinical Excellence Operations, St. Louis, MO, United States
AHendrich@ascensionhealth.org

Marylyn P. Chow
Kaiser Permanente, Patient Care Services, Oakland, CA, United States
Marilyn.P.Chow@kp.org

Keywords
hospital unit; nurses' movement; statistical analysis; space planning

Abstract

Optimization of nurses' movement is an important means for improving organizational productivity in healthcare units. Studies on movement and behavior of nurses have often found that the spatial layout of nursing unit floors has a significant effect on nurses' mobility. However, efforts to correlate types of hospital layouts with nurses' movement have not met with consistent success. We show that the effect of spatial layout on nurses' movement can be modeled with far greater predictability and consistency if the unit of correlational analysis is not the gross scale of the entire unit floor, but at the finer scale of an "assignment:" i.e. the specific set of rooms to which individual nurses are assigned during a shift. Choosing a nurses' assignment as a unit of analysis follows our main argument that nurses will modify or adapt their behavior according to the characteristics of the area within which they work, rather than to an entire floor plate typology. This paper presents a study that demonstrates this argument empirically. The study is based on an analysis of data collected as part of a Time and Motion study organized by Ascension Health and Kaiser Permanente, from medical-surgical nursing units located in 36 clinically diverse hospitals. Movement patterns were captured using RFID tags worn by nurses, producing time-sequence spatial data that provide a nurse's location and time when the nurse comes in the location and went out of the location with a time stamp. From this data, we used 143 individual nurses' shifts in five of these units to model the frequency of visits made by nurses to their assigned patient rooms. We found that a generalized linear model with a Poisson distribution function and log link function best predicted frequency of nurse entries to patient rooms, using a linear combination of linear segregation, visual connectivity, distance in number of turns to nursing station, and the number of rooms assigned per shift as the explanatory variables. A methodological innovation of our approach—made possible by choosing the 'assignment' as a unit of analysis—was to create a single model for data drawn from all five units, thus allowing us to treat integration and connectivity on absolute scales, rather than on scales

relative to their spatial settings. Thus, not only were we able to demonstrate that each of syntactical variables significantly influenced the frequency of nurse visits—as is conventional in space syntax studies—we were able to offer quantitative estimates of the frequency of visits to assigned patient rooms along with their individual probabilities. Our work suggests that with further studies of this kind, it should be possible to develop models that can estimate the effect of space planning and distribution on nurses' behaviors.

1. Role of spatial organization on nurses' movement

In the health care system, especially medical surgical units, nurses have the greatest amount of direct contact with patients and thus nurse planning has a direct effect on patient care and safety. Many empirical studies have investigated the effects of organizational attributes such as nurse-to-patient ratio, staffing skill mix, and organizational policies on nurses' productivity (Aiken 2002; IOM 2004). In addition to the organizational attributes, the amount nurses walk during work has also been found to affect their productivity. According to Burgio (1990), nurses spend almost 28.9 % of their nursing time on walking. Owing to the mobile character of nurses' tasks, the space layout of a hospital unit can have a significant effect on nurses' performance. This claim has been supported by previous research that analyzed the effects of spatial organization on nursing activities in the hospital ward. Seelye (1982) reviewed studies on the hospital ward layout in relation to nurse staffing and concluded that short travel distances are one of the measures of ward layout in terms of the effectiveness and efficiency of nursing care. Through empirical studies, Sturdavant (1960), Jaco (1972), and Shepley (2003) found that nurses made fewer trips in a circular ward layout due to global visibility than in a rectangular ward layout. However, efforts to correlate types of hospital layouts with nurses' movement have not meet with consistent success. Nuffield Provincial Hospital Trust (1955) studied the effect of ward designs on travel patterns of nurses, and concluded that the proportion of trips made by nurses to different wards was similar regardless of their design. Recently, Hendrich et al (2008) collected the data of nurses' behavior in 36 study units and did not find a statistically significant relationship between the three layout types (into which they had classified their sample) and nursing time spent with patients. In sum, it has been acknowledged in principal that the space layout of a hospital unit affects nurses productivity by influencing the total percentage of time they spend their work time in walking as well as their ability to "keep an eye" on their tasks. Yet, we have not found any studies that can allow us to assess the comparative benefits of one floor layout over another in this context. We believe that since nurses work and move within a certain sub-area of the unit to which they have been assigned they are more likely to modify or adapt their movement according to characteristics of that area, rather than to the design of an entire medical unit or floor layout. This can be possibly why no significant correlations are found consistently between types of unit and nurses' movement patterns within them. We also argue that broad typological categorizations of designs do not capture the social and perceptual complexity that nurses employ when navigating through their workspace. For the aim of investigating the relationship between space planning and nurses movement, we hence employ two novel techniques: First, we consider only the sub-area within which a nurse moves, and second, instead of travel distances, we use syntactic properties of that sub-area.

2. About the dataset

The study is based on an analysis of data collected as part of a Time and Motion study organized by Ascension Health and Kaiser Permanente, from medical-surgical nursing units located in 36 clinically diverse hospitals. Movement patterns were captured using RFID tags worn by nurses, producing time-sequence spatial data that provide a nurse's location and time when the nurse came in the location and went out of the location with a time stamp. From the data from the time and motion study, we used 143 individual nurses' shifts in five of these units to model the frequency of visits made by nurses to their assigned patient rooms. Figure 1 shows the layouts of the five nursing units which can be considered as rectangular wards. Within this category, only unit 4 is a single-corridor type while the others are a double-corridor type. Among the double-corridor type of plans, axial maps reveal different spatial characteristics. Two parallel corridors in the unit 2 are equally central with respect to the entire unit whereas two parallel corridors in the unit 3 and 4 are unequally central mainly due to asymmetric unit configuration. Connectivity graphs of the five units in Figure 2 show visual exposure of each node in the five units. Unit 1, 2, and 3 have a centralized nurse station and support spaces while unit 4 and 5 have decentralized nurse stations and support spaces.

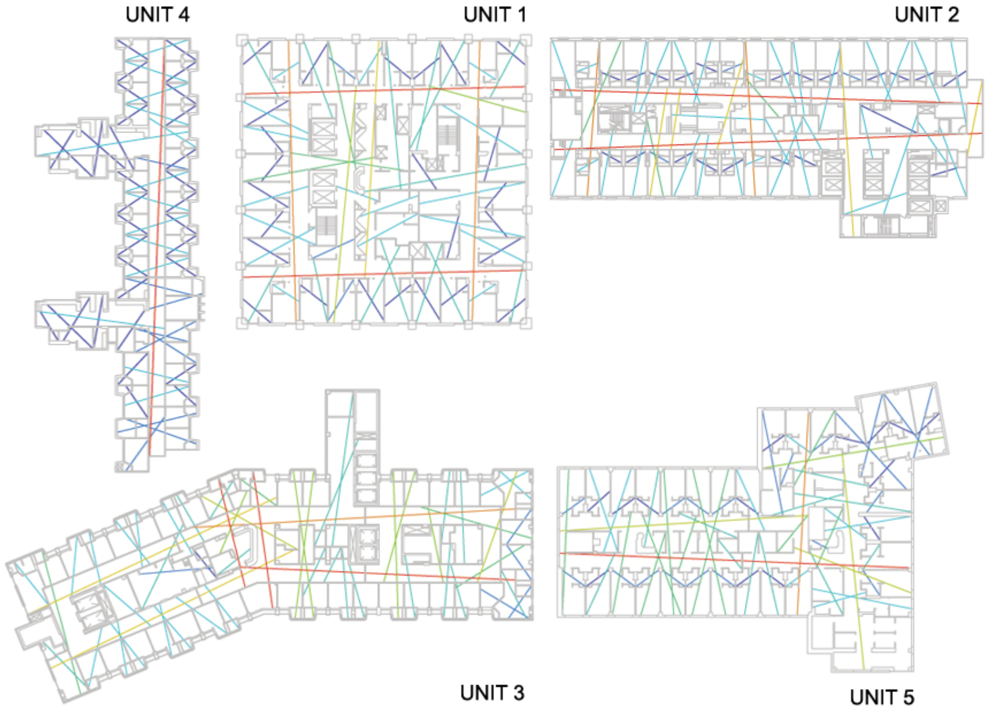

Figure 1
Layouts of the five units with axial lines

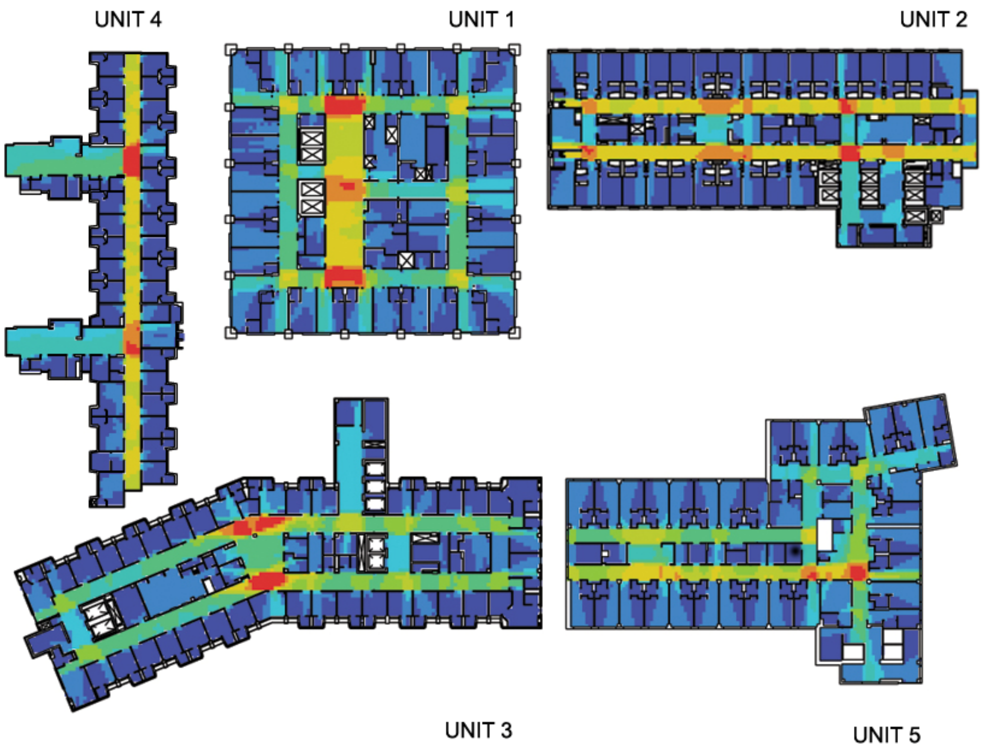

Figure 2
Connectivity graphs of the five units

3. Rationale and process of using "assignment" as a unit of study

The objective of this study is to investigate the effects of spatial layouts on nurse movements. To start with, we need to determine the right resolution at which the spatial properties of a hospital unit begin to influence nurses' movement. Most analytic models in the current literature consider the design of the entire hospital unit. These models are process models, and are designed to evaluate the effect of organizational strategies on the efficiency of the care-giving process (Groothuis 2002; Komashie 2005; Seupulveda 1999; Wiinamaki 2003). Their reason for taking the entire nursing unit as the unit of analysis is reasonable because the influence of organizational strategies on nurses can be regarded as identical throughout the unit. We assumed, however, that the movement of a nurse would depend upon specific and local properties of space, such as the distance between patient rooms, the number of turns between different destinations in the unit, or visual field available from specific areas of the unit. Any simulation of the nurse movement would have to take such spatial attributes into account. As the first step, data from one surgical medical unit, unit 5, was selected for an exploratory pilot study. Our specific aim was to see if we could establish the effect of spatial properties of a nurse assignment on his/her behavior with some confidence. Since all the assignments were taken from the same unit, we could assume that unit-wide factors (such as other organizational criteria) were the same for all the assignments. We ignored for this study potential differences in behavior due to individual nurses, assuming that the data collected had randomized the nurses. In unit 5 the rooms are pre-divided into assignment sets, consisting of adjacent rows of five rooms. Although different nurses are assigned to each set, the actual set of rooms in a particular assignment remains fixed. As for the movement itself, nurses' work areas within a unit can be categorized into two groups: Patients' rooms where nurses provide direct contact and care to patients and Nurses' areas where nurses fulfill their tasks supporting the care process. As shown in the left side of Figure 3, this general level of grouping creates three different types of trips, a trip being movement undertaken by a nurse with a specific origin and destination: (1) from patients' rooms to patients' rooms, (2) from patients' rooms to nurses' areas, and (3) from nurses' areas to nurses' areas.

In the actual layout of the hospital unit, nurses' areas consist of several separate types of rooms. In this study, three distinct groups of service areas, stations, medication rooms, and utility rooms, are considered since they correspond to the highest frequency of visits. This detail categorization of work areas with patient rooms produces ten different paths: (1) from patients' rooms to patients' rooms, (2) from patients' rooms to stations, (3) from patients' rooms to medication rooms, (4) from patients' rooms to utility rooms, (5) from stations to stations, (6) from stations to medication rooms, (7) from stations to utility rooms, (8) from medication rooms to medication rooms, (9) from medication rooms to utility rooms, and (10) from utility rooms to utility rooms. These ten paths can be directly mapped to the layout plan as the physical movements. These ten paths are analyzed to capture the actual nurse movement patterns in relation to spatial characteristics of the unit layout and the paths.

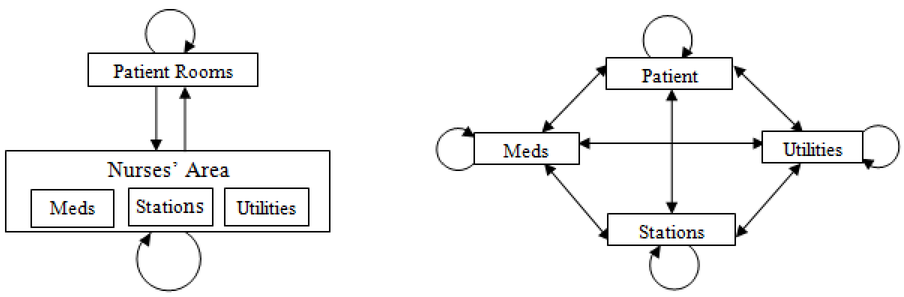

Figure 3
Structure of movements among a group of work areas

According to the framework of categories, we processed the data collected by RFID in the five units to derive the frequency of trips on a particular path shown in the diagram at right in Figure 3. Then, several frequencies of trips can be grouped into a general level of category shown in the diagram on the left in Figure 3. Figure 4 shows the three box plots of the number of visits: the number of visits from assigned patient rooms to assigned patient rooms, the number of visits from assigned patient rooms to nurse areas, and the number of visits from nurse areas to nurse areas. The graphs clearly indicate a variation of the number of trips due to different assignment although a deviation on the number of trips within one assignment, of course, exists due to different nurses' characteristics and work load.

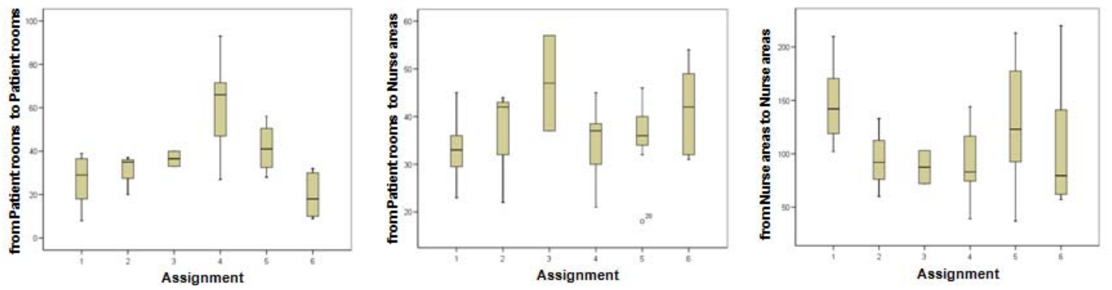

Figure 4
Three box plots of the number of visits: the number of visits from assigned patient rooms to assigned patient rooms (left), the number of visits from assigned patient rooms to nurse areas (middle), and the number of visits from nurse areas to nurse areas (right)

This exercise led us to hypothesize that over and above differences due to individual nurse characteristics and the work load, the spatial characteristics of the assignment would also explain the variation in nurses' movement patterns. We selected five syntactic variables to characterize the spatial quality of a particular assignment: axial integration, visual connectivity, path distance, path visibility (by visual step depth), and the number of turns. Axial integration is a key morphological variable, and it characterizes the centrality of a space within a configuration. Here it is measured in terms of relative number of turns one reaches to go from assigned patient rooms to all others. Visual connectivity is a local measure which captures the amount of space directly visible from each node. It is measured in terms of number of points visible from patient rooms. While these two variables are representatives of local spatial characteristics on the patient rooms assigned, the other three syntactic variables explain spatial attributes of a path in each assignment: path distance, visual step depth of the path, and number of turns in the path. Each assignment has its own ten paths with different spatial characteristics quantified by the three syntactic descriptors. Figure 5 is a scatter plot on the three spatial descriptors' values of the ten paths for all assignments. It indicates that the three syntactic variables representing the path characteristics have strong correlations within the same layout of the pilot study. Therefore, the path distance is used as the single descriptor encompassing all the three properties associated with the path.

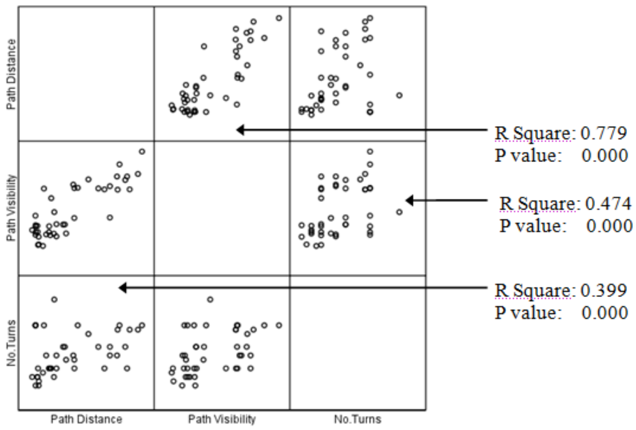

Figure 5
Scatter plot of three syntactic variables of the paths

Table 1 shows the results of regression analysis between syntactic variables and frequency of visits for the ten paths. For the path from patients' rooms to patients' rooms, the number of trips is inversely proportional to the visual connectivity as indicated in Figure 6. For the paths from nurses' areas to patient rooms, three scatter plots in Figure 7 reveal the effects of contiguity on frequencies of trips. Also, the results of regression analysis indicate that a variation of the number of visits on the three paths has a significant correlation with a variation of path distance.

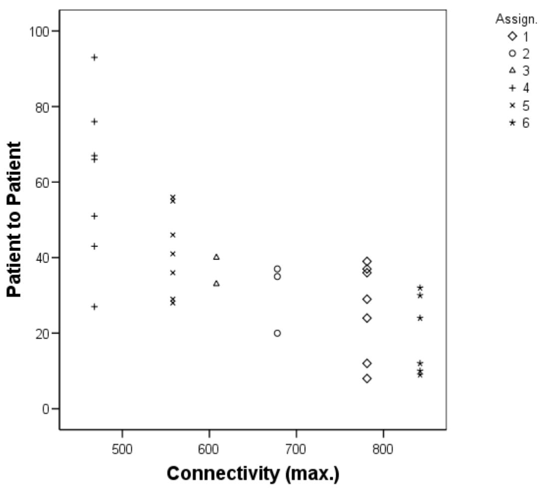

Figure 6
Scatter plot of connectivity and the number of trips by assignment

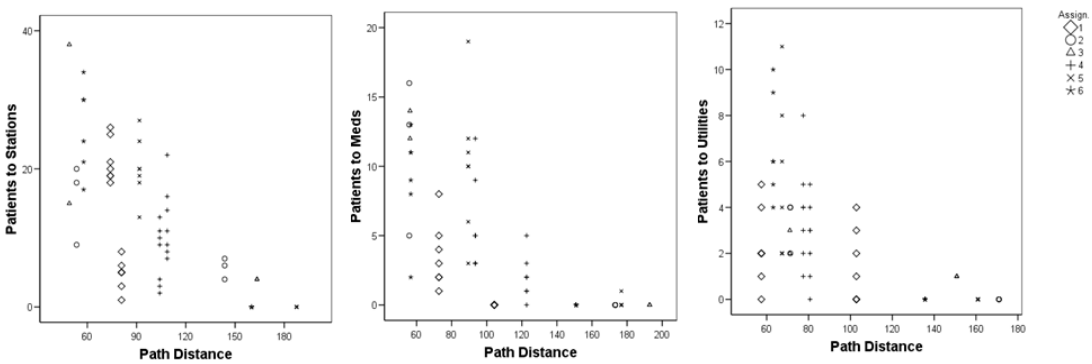

Figure 7
Scatter plots of path distance and the number of trips by assignment: trips from patients' rooms to stations (left), to meds (mid), and to utilities (right)

Among paths from nurses' areas to nurses' areas, both the path distance and the distance from assigned patient rooms to the starting location of the path are used as independent spatial variables for regression analyses. We believe that patients' rooms assigned are a base for a nurse and a nurse makes strategies for movement patterns in nurses' areas according to spatial relationship between patients' rooms and nurses' areas. Table 1 proves that visual connectivity and path distance are significant factors in determining the frequencies of the trips on the paths as suggested by t values of all the independent variables in the regression analyses. However, the two paths from stations to stations and from stations to meds have a high R^2 value while the other four paths have a small R^2 value below 0.20. The reason that R^2 values are so low in the four paths can be due to other factors playing a more significant role in explaining the frequencies. It is arguable that the lower coefficients of determination (R^2) for trips to and from utilities or medication stations show that such trips are determined by emergencies of the situation, whereas trips to and from patient rooms might be generated partially depending on spatial configuration of the unit.

Path name	R^2	Variables	Unstandardized coefficients		t	Significance at 95% level
			B	Std. Error		
Patients to Patients	0.518	(Constant)	101.723	11.674	8.713	Yes
		Connectivity	-0.099	0.017	-5.680	Yes
Patients to Stations	0.547	(Constant)	30.071	2.297	13.092	Yes
		Path distance	-0.173	0.020	-8.661	Yes
Patients to Meds	0.443	(Constant)	12.810	1.319	9.714	Yes
		Path distance	-0.078	0.011	-7.018	Yes
Patients to Utilities	0.382	(Constant)	6.782	0.736	9.221	Yes
		Path distance	-0.044	0.007	-6.184	Yes
Stations to Stations	0.355	(Constant)	31.346	3.356	9.342	Yes
		Path distance	-0.142	0.020	-7.084	Yes
		Distance from P	-0.118	0.027	-4.321	Yes
Stations to Meds	0.450	(Constant)	20.507	1.865	10.995	Yes
		Path distance	-0.103	0.012	-8.834	Yes
		Distance from P	-0.063	0.015	-4.264	Yes
Stations to Utilities	0.171	(Constant)	2.941	0.441	6.663	Yes
		Path distance	-0.016	0.004	-4.104	Yes
		Distance from P	-0.008	0.003	-2.669	Yes
Meds to Meds	0.189	(Constant)	2.472	0.436	5.664	Yes
		Path distance	-0.010	0.002	-4.507	Yes
		Distance from P	-0.010	0.003	-2.982	Yes
Meds to Utilities	0.194	(Constant)	4.954	0.784	6.318	Yes
		Path distance	-0.029	0.006	-4.997	Yes
		Distance from P	-0.013	0.005	-2.304	Yes
Utilities to Utilities	0.137	(Constant)	1.214	0.245	4.955	Yes
		Path distance	-0.007	0.002	-3.816	Yes
		Distance from P	-0.005	0.002	-2.310	Yes

Table 1
Results of regression analysis for the ten paths

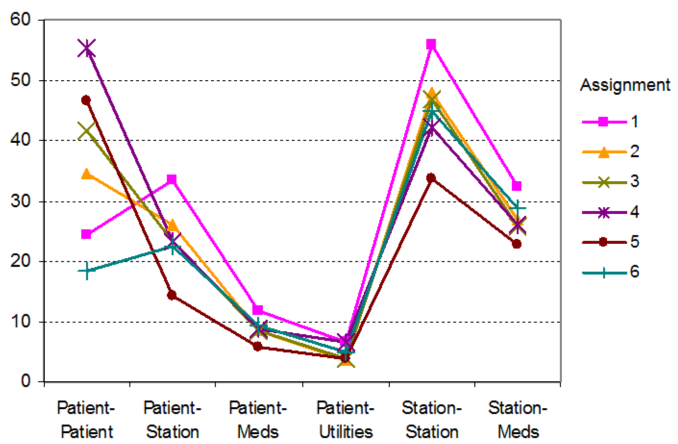

Figure 8
The number of trips for the six paths for assignments by the function

Among the ten paths, the six paths that have a large R^2 value are chosen to examine a variation of nurse movement patterns within one unit due to local spatial features. Six functions derived from regression analysis are applied to represent a nurse movement pattern of each assignment in relation to spatial features. Through comparison with an average number of trips on the path, the six functions are verified to adequately represent the real nurse movement patterns for all the assignments. The results show that visual connectivity, path distance, and distance from assigned patient rooms to the starting location of the path have a significant impact on the frequency of trips on the six paths. From Figure 8, we can see local spatial properties can explain the amount of variation in the number of trips for nurse movement patterns. Comparatively small deviation in the number of trips exists in the three paths, from patients' rooms to meds, from patients' rooms to utilities, and from stations to meds among the six paths. However, in the other three paths, from patients' rooms to patients' rooms, from patients' rooms to stations, and from stations to stations, difference of local spatial features by assignment causes a substantial deviation in nurse movement patterns. Therefore, since the frequencies of trips are enormously different by assignment, one common nurse movement pattern as a unit level cannot represent all nurses' movement patterns in one hospital unit without consideration of local spatial properties.

4. The Statastical Model

Our pilot study showed that assignment related spatial properties do explain significant aspects of a nurse's movement and, of various components of the movement, the trips to and from patient rooms were most strongly explained by the spatial properties. To test this finding from the pilot study we used data from all the five units to model frequency of trips made by nurses to their assigned patient rooms as a function of syntactic properties of the assignment. The statistical model is thus based on 143 individual nurses' shifts in the five units. It uses the assignments as the unit of analysis; in this case, the assignment refers to one eight-hour shift during which a nurse is assigned to a certain set of patient rooms. Another reason to select the number of trips to patients' rooms is that these trips can be directly related to chances of providing a direct care to patients.

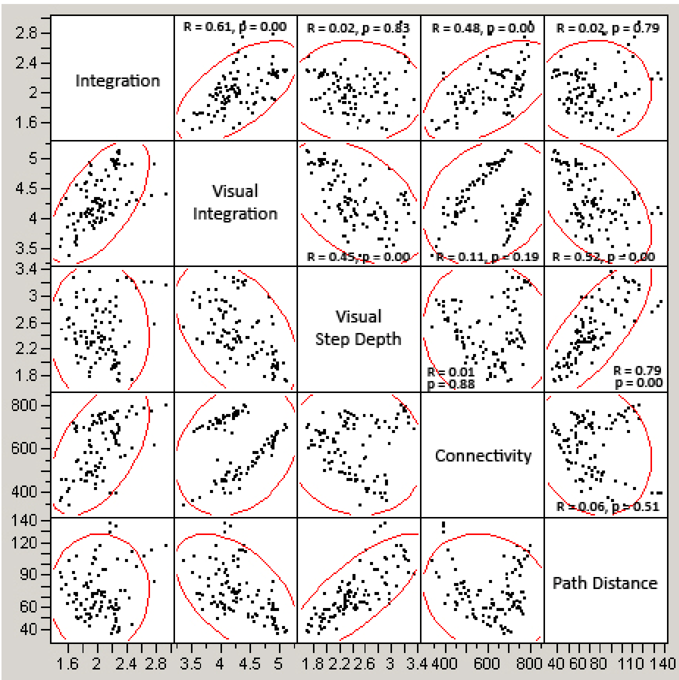

Figure 9

Multivariate scatter plot of five syntactic variables

For explanatory variables, we initially studied five syntactic variables: linear integration, visual integration, visual connectivity, visual step depth, and path distance. Linear integration was calculated as the average of all integration values crossing patient rooms assigned. Visual integration was the average of all visual integration values in assigned rooms. Visual connectivity was calculated by averaging connectivity values of all nodes in assigned rooms. Visual step depth and path distance were the averages of all visual step depth values and distances from assigned rooms to the nearest nurse station respectively. These two variables were selected to capture the spatial relations between patient rooms and stations, both of which nurses visit most during a shift. The number of rooms assigned to a nurse was also added as an additional explanatory variable, since nurse-to-patient ratios have been found a key variable impacting nursing staffing and the quality of care (Aiken 2002; IOM 2004).

Correlations between these explanatory variables were examined in order to increase the reliability of a statistical model. Multivariate scatter plot in Figure 9 shows a correlational analysis among the five syntactic variables. Linear regression analysis showed that linear integration and visual integration were highly correlated ($R=0.61$, $p=0.00$) and visual step depth and path distance were also strongly correlated ($R=0.79$, $p=0.00$). As a result, the statistical model used four explanatory variables: linear integration, visual connectivity, visual step depth, and the number of rooms.

A generalized linear model (GLM) with a Poisson distribution and log link function was used to build the statistical model. Generalized linear models are an extension of traditional linear models that allows the probability distribution of a response variable to be any member of an exponential family of distributions. Traditional linear models generally used in statistical data analysis cannot be applied to our study since they are not suitable for modeling discrete count data. (In our model, the number of entries to patient rooms is count data and assumed to follow a Poisson distribution)

The GLM we have developed predicts the number of entries to assigned patient rooms, using linear segregation, visual connectivity, visual step depth, the number of rooms, and a unit factor for each hospital unit. Instead of linear integration, we used RRA, or linear segregation, whose value for each room is the value of the most segregated line passing through the room. The main reason for using segregation was to allow easier interpretation of the results. Accordingly, low segregation values refer to high centrality. Also, although one key organizational characteristic, a nurse-to-patient ratio, is included in the model, one variable may not still be enough to capture all differences among the units due to various organizational strategies. Thus, unit factors are included in the model to account for such differences. Also, in order to compare the effects of an explanatory variable, all the explanatory variables are standardized to z-scores. Z-score is calculated by subtracting the mean from a raw value and then dividing by the standard deviation.

In order to validate the statistical model, we conducted two tests, an omnibus test and a deviance residual plot. Table 2 shows the result of the Omnibus test guaranteeing that variance explained by the statistical model is significantly greater than unexplained variance. Also, the random distribution of the deviance residuals in Figure 10 proves the validity of the statistical model.

Likelihood Ratio Chi-Square	Df	Sig.
462.066	8	.000

Table 2

Omnibus test for entries to assigned patient rooms

Table 3 shows the results of the statistical model for the number of entries to assigned patient rooms. The results demonstrate that all the three syntactic variables and the number of rooms are statistically significant in relation to the frequency of the entries. Among them, the organizational feature, the number of rooms, has a stronger effect on the frequency of the visits than all the syntactic variables. Then, connectivity, integration, and visual step depth have higher effects on the frequency in order.

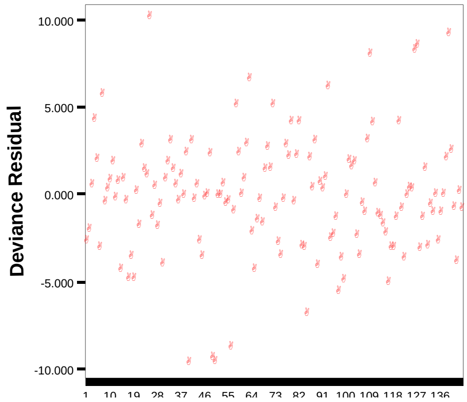

Figure 10

Deviance residual plot for entries to assigned patient rooms

The total number of entries to assigned rooms has positive correlations to integration and the number of assigned rooms but negative increases to connectivity and visual step depth. In detail, when the number of rooms doubles, the number of entries to assigned rooms increases by 14% respectively. But, the number of entries to assigned rooms decreases by 8%, 6%, and 8% when the segregation, the visual step depth, and the connectivity, double respectively. Those percents are odds ratios that are the model b coefficients raised to the power of the natural logarithm. The ratios are commonly used to interpret the effects of explanatory variables for a loglinear model. In conclusion, the model demonstrates that a nurse visits assigned patient rooms less when those rooms are less central with respect to the entire layout, less approachable to nurse stations, or more visually exposed to other spaces in the unit. We can conclude that the centrality of patient rooms and approachability of assigned rooms to nurse stations can provide more chances of direct care, but the visual exposure of assigned rooms can cause more chances to distract nurses from direct care to assigned patients.

Parameter	Estimate	Std Error	L-R ChiSquare	Prob>ChiSq	Lower CL	Upper CL
Intercept	4.239	0.012	40256.189	0.000	4.215	4.263
UNIT[1]	-0.021	0.024	0.753	0.386	-0.067	0.026
UNIT[2]	0.066	0.047	1.927	0.165	-0.027	0.158
UNIT[3]	0.064	0.041	2.476	0.116	-0.016	0.144
UNIT[4]	0.042	0.024	3.049	0.081	-0.005	0.088
Std NoRooms	0.134	0.014	91.319	<.0001	0.107	0.161
Std Segregation	-0.086	0.015	32.428	<.0001	-0.116	-0.057
Std Min(Visual.Step.Depth.fr.Station)	-0.058	0.015	15.237	<.0001	-0.087	-0.029
Std Avg(Connectivity.Avg)	-0.086	0.029	8.821	0.003	-0.143	-0.029

Table 3

Parameter estimates for entries to assigned patient rooms

5. Conclusions

This paper has presented a research framework that is intended to incorporate spatial parameters with organizational parameters in a process model of nursing care by defining the relationships between spatial characteristics of the physical layout and nurses' movement. The data from the five units were analyzed as an exploratory pilot study. The pilot study proved that spatial characteristics of the hospital unit have a significant impact on nurse movement patterns by demonstrating the fine resolution relations of local spatial attributes to the frequency of visits to assigned patient rooms. A methodological innovation of our approach—made possible by choosing the 'assignment' as a unit of analysis—was to create a single model for data drawn from all five units, thus allowing us to treat integration and connectivity on absolute scales, rather than on scales relative to their spatial settings. Thus, not only were we able to demonstrate that each of syntactical variables significantly influenced the frequency of nurse visits—as is conventional in space syntax studies—we were able to offer quantitative estimates of the frequency of visits to assigned patient rooms along with their individual probabilities. Our work suggests that with further studies of this kind, it should be possible to develop models that can estimate the effect of space planning and distribution on nurses' behaviors.

Acknowledgments

This analysis reported here was conducted on data collected for a larger Time and Motion Study undertaken by Ann Hendrich at Ascension Health and Marylin Chow at Kaiser Permanente to investigate how medical-surgical nurses spend their time, and to see what effect the architecture of the unit had on their movement patterns. Parts of this study were funded by grants from the Robert Wood Johnson Foundation and the Gordon and Betty Moore Foundation. We are indebted to Wendy S. Goshert, National Time & Motion Study Coordinator, Health Evolutions and Dr. Craig Zimring, Professor, Georgia Tech College of Architecture for their help with the project. Boguslaw Skierczynski, PhD, Biostatistician, Ascension Health, and Zhenqiang Lu, PhD, Visiting Assistant Professor of Statistics, Purdue University provided substantive statistical validation and sorting of the raw movement data and gave helpful feedback throughout the analysis.

References

Aiken, L., Clarke, S., Sloane, D., 2002, Hospital Staffing, organization, and quality of care: cross-national findings, *Nursing Outlook*, 50(5):187-194

Burgio, L., Engel, B., Hawkins, A., McCorick, K., and Scheve, A. (1990) A descriptive analysis of nursing staff behaviors in a teaching nurse home: differences among NAs, LPNs, and RNs. *The Gerontologist*, 30:107-112.

Groothuis, S., Goldschmidt, H., Drupsteen, E., Vries, J., Hasman, A., and Merorde, G. (2002) Application of computer simulation analysis to assess the effects of relocating a hospital phlebotomy department. *Annals of Clinical Biochemistry*, 39(3):261-272.

Hendrich, A., Chow, M., Skierczynski, B., and Lu, Z. (2008) A 36-hospital time and motion study: How do medical-surgical nurses spend their time? *Permanente Journal* 12(3):25-34.

Institution of Medicine (IOM), 2004, Keeping patients safe: transforming the work environment of nurses, The National Academies Press, Washington, USA

Jaco, E. G. 1972, Ecological aspects of patient care and hospital organization, *Organization Research on Health Institutions*, Michigan, Institute of Social Research.

Komashie, A., Mousavi, A. (2005) Modeling emergency departments using discrete event simulation techniques. *Proceedings of the 2005 Winter Simulation Conference*, 2681-2685.

Nuffield Provincial Hospitals Trust (1955) *Studies in the functions and design of hospitals*. Oxford University Press. London.

Seelye, A. (1982) Hospital ward layout and nurse staffing. *Journal of Advanced Nursing*, 7:195-201.

Seupulveda, J., Thompson, W., Baesler, F., Alvarez, M., and Cahoon, L. (1999) The use of simulation for process improvement in a cancer treatment center. *Proceedings of the 1999 Winter Simulation Conference,* 1541-1548.

Shepley, M. M. and Davies, K. (2003) Nursing unit configuration and its relationship to noise and nurse walking behavior: an AIDS/HIV unit case study. From http://www.aia.org/aah_a_jrnl_0401_article4

Sturdavant, M. (1960) Intensive service in circular and rectangular units compared. *Hospitals* 34, 46-48;71-78.

Wiinamaki, A. and Dronzek, R. (2003) Using simulation in the architectural concept phase of an emergency department design. *Proceedings of the 2003 Winter Simulation Conference*, 1912-1916.