Centralization of Intensive Care Units: Process Reengineering in a Hospital

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Abstract: *Centralization of intensive care units (ICUs) is a concept that has been around for several decades and the OECD countries have led the way in adopting this in their operations. Singapore Hospital was built in 1981, before the concept of centralization of ICUs took off. The hospital's ICUs were never centralized and were spread out across eight different blocks with the specialization they were associated with. Coupled with the acquisitions of the new concept of centralization and its benefits, the hospital recognizes the importance of having a centralized ICU to better handle major disasters. Using simulation models, this paper attempts to study the feasibility of centralization of ICUs in Singapore Hospital, subject to space constraints. The results will prove helpful to those who consider reengineering the intensive care process in hospitals.*

Keywords: *Centralization, intensive care units, simulation, resource optimization*

1. Introduction

With escalating healthcare costs, hospitals are seeking ways to contain costs and provide quality healthcare services. Hospitals have traditionally emphasized breakthroughs in healthcare procedures and technology to stay competitive. As competition among hospitals continues to intensify, however, patients may perceive little difference in healthcare procedures and technology used by different hospitals. Consequently, hospitals come to understand that process reengineering could be a better solution to achieve competitive advantage. Computer simulation, which has proven successful in improving various business processes, can also be an effective tool in searching for more efficient processes in hospitals (Kumar *et al.*, 2005a, 2005b, Kumar and Shim, 2005, 2006, and Kumar *et al.*, 2008).

From the beginning of organized nursing care, it was recognized that nurses were able to provide the best nursing care if the sickest patients were placed closest to the nursing stations, often with a higher nurses/patients ratio for the patients. Based upon this concept, both the surgical recovery room and the critical care unit have developed and withstood the test of time. Today, more than 10% of acute inpatient beds are devoted to critical care (Kumar *et al.*, 2005b), and the number of patients requiring intensive care is predicted to double by year 2020 as the elderly population grows in many industrialized countries (Breslow and Doefler, 2003). Nevertheless, the rapid growth of the number of as well as the acuity of patients treated in ICUs has created severe pressures on hospitals. There is a large inter-hospital variability in intensive care processes and an inconsistency in the quality of intensive care received by patients. Severe shortages of quality nurses and physicians trained to care for the critically ill further complicate the intensive care delivery in many countries (Pronovost *et al.*, 2004). Further, the multiplicity of critical problems in intensive care patients often necessitates the involvement of multiple practitioners and specialists. Coordinating the activities of these diverse medical practitioners and specialists and establishing the correct balance between competing priorities require consistent and knowledgeable oversight and effective communication amongst the participants (Breslow and Doerfler, 2003). Nevertheless, many studies that were conducted at individual hospitals worldwide indicate the high cost of intensive care (Gyldmark, 1995). Thus, there is a need for sustainable improvements in the process of intensive care with optimum cost.

Singapore Hospital (referred to as 'the Hospital' hereafter, for brevity) was built in 1981. It admits about 60,000 patients each year and about 600,000 are attended to its specialist outpatient clinics. With about 1,400 beds and a pool of about 450 specialists, it takes referrals from primary healthcare physicians as well as specialists. The intensive care units (ICUs) form an integral part of the Hospital, as they are needed for administration of care that relates to the ongoing management of physiological abnormalities of patients. The ICUs in the Hospital have a total of fifty-five beds for adult care and eight beds for paediatrics. The ICUs for adult care are grouped into six different departments:

- Surgical intensive care unit (SICU) - 10 beds
- Cardio thorax intensive care unit (CTICU) - 17 beds
- Neurology intensive care unit (NICU) - 8 beds
- Cardiac care unit (CCU) - 8 beds
- Burns intensive care unit (BICU) - 4 beds
- Medical intensive care unit (MICU) - 8 beds

The need for a centralised ICU was highlighted during the Jakarta bomb blast when many of the victims were flown over to Singapore for treatment. Many of the victims suffered from third degree burns and the Hospital had the capabilities of handling them better. The problem was that there were only four ICUs catering for burns in the Hospital. The problem was exacerbated when some patients developed complications, which sometimes required operations. Also, ICUs for burns patients were situated at BLK 4 Level 3, whereas most of operation theatres were located at BLK 2 Level 2. Therefore, after operations, patients had to be relocated back to BLK 4. Some ICUs were available next to operating theatres but they were not for handling burns patients.

Centralization of ICUs can benefit patients in the day-to-day operations in the Hospital in the same way as it can benefit victims suffering from disasters. The reduction of transit time for patients may prove crucial in their chances to survive. Centralization plans, however, can be hampered by a variety of constraints such as space, costs and staffing. Cost of relocating ICUs in a centralized location may prove to be hefty, but the Hospital can consider it as an investment to upgrade facilities and capabilities. In terms of staffing, the Hospital is severely understaffed and considers hiring more hands. The Hospital may not be able to release nurses and doctors for retraining, which is necessary for them to work in a centralized ICU with cross-department skills. The problem of staffing can be alleviated due to the high costs of relocation, compared to the space constraints.

Using simulation models, the process of centralization of ICUs in the Hospital was tested to determine the optimum number of ICUs required for daily operations and to see any possibility to fit the optimum number of ICUs into the proposed area of centralization. Also, a simulation model of patent admission was developed to predict the flow of patients into ICUs and the occupancy rates in ICUs.

2. Literature Review

The structure and organization of ICUs are diverse and vary among countries. In describing the structure of ICUs in the U.S., Pollack *et al.* (1993, 1987) reported that the largest proportion (40%) of ICUs had four to six beds per unit, while only 6% had more than eighteen beds per unit. Only 79.6% of ICUs had full-time medical directors. An intensivist was available to 73% of the units. As the size of ICUs increased, the estimated mortality rates increased and the percentages with full-time directors, intensivists, and 24 hours/day dedicated coverage increased. Groeger *et al.* (1992) also reported that the number of ICUs per hospital increased along with the overall size of hospitals and that the smallest hospitals (less than 100 beds) usually had only one ICU.

Depasse *et al.* (1998) evaluated similarities and differences between Western European countries in ICU nurse staffing, education, training, responsibilities and initiative. Their findings revealed that among British ICUs, 79% had more than three full-time nursing equivalents (FTE) per ICU bed; while in Sweden 75% of units had less than two FTE per ICU bed. There were variations in nurse staffing patterns among European countries and in their systems of training and education. Krupicka *et al.* (2002) studied the impact of a clinical pharmacist in an ICU. The goals of the study were to determine the type and quantity of patient care interventions recommended by the clinical pharmacist and to examine cost savings. They concluded that the pharmacist is an important and cost-effective member of the ICU team. Pronovost *et al.* (2004) also evaluated the perspective of hospitals on the costs and savings of implementing intensivist staffing, which resulted in cost savings to hospitals as well as significant reductions in patient mortality rates.

Many investigators have studied the centralization and integration of ICUs and the resulting improved outcome. Pearson *et al.* (2001) compared ICU admissions from a defined population of children in 1991 and 1999, during a period of organizational change and centralization of paediatric ICUs. Their findings highlighted that the centralization by expansion of the lead centre resulted in a large increase in the number of children receiving intensive care and a fall in child mortality over the period. Gemke *et al.* (1997) identified that the outcome of critically ill children treated in tertiary paediatric ICUs is superior to that of those treated in other settings, and suggested that the centralization of care is necessary to improve the quality of care.

Further, Goh and Mok (2001) discussed that the physicians at local hospitals in UK within a centralized system of delivering intensive care were able to maintain adequate assessment skills in recognition and requesting for transfer of the most ill and efficiently utilized resources available at the regional centre. Breslow and Doerfler (2003) described that the two core concepts embodied in centralized ICU care are the use of permanently staffed centre to oversee patients in multiple ICUs simultaneously and the utilization of information technologies to identify problems early and direct caregivers to best practices. Furthermore, Jacobs *et al.* (2004) used standardized costing data across seventy-two ICUs and combined units in UK and observed an association between cost per patient day and economies of scale. Additionally, there was a relationship between the scale of ICUs and the health outcomes of patients. Laukontaus *et al.* (2007) tried to determine whether organizational changes in favour of centralization of emergency vascular services could improve the outcome of treatment of ruptured abdominal aortic aneurysm. Their results supported the centralization of emergency services.

Managing ICUs is a difficult task, because each ICU is highly complex and its environment is tense. Modern ICU management requires the development and implementation of a multi-centre information system that can provide data on how resources are being used in

relation to their availability (Maybloom and Champion, 2003).

Healthcare is a dynamic system with complex interactions, in which the simulation technique would play an indirect but vital role to achieve the optimal result. The real power of the simulation technique is fully realized when it is used to study a complex system (Kelton *et al.*, 1998). Healthcare service providers have successfully employed the simulation technique to help understand and optimize various healthcare processes (Kumar and Shim, 2005; Kumar and Shim, 2006; Kumar *et al.*, 2008). Blake *et al.* (1996) also describe a simulation model of the emergency room to investigate issues contributing to patient wait times. Lane *et al.* (2000) describe a simulation model to understand patient wait times in an accident and emergency department.

Given the increasing demand by patients on intensive care services and the acute shortage of manpower in the local healthcare industry, the Hospital considers centralizing its ICUs in order to utilize existing resources more efficiently.

3. Modelling of the Intensive Care Units

Arena® is a simulation software tool widely used for evaluating, planning and designing the processes in hospitals and other healthcare systems. Its graphics animations allow users to visualize the process flow and breakdowns. Patients are admitted into the ICUs of the Hospital from various channels. Most patients are admitted for further monitoring of their progress after a serious operation like multiple bypass surgery, while others are admitted through the accident and emergency department. Some are also transferred from other ICUs or normal wards as their conditions deteriorate. The entry of patients into the ICUs is modeled, using the general admission of patients into the ICUs as a guide to see how many beds are occupied throughout the year. Several modules of Arena® are used in the simulation model.

The Create Module in the basic process panel is used to simulate the admission of patients into the Hospital. The entities per arrival are set to one patient per arrival. The maximum number of arrivals is set to infinity on the assumption that the Hospital does not refuse admission of patients.

Modeling of admitted patients into the different ICUs is done by using the Decide Module. The Decision Module utilizes the N-way by chance, which is the essential ratio of patients admitted to the different ICUs. Patients are routed to the different ICUs that simulate the length of stay of each patient based on the statistical input in the Process Module. The *Decide Module* includes options to make decisions based on one or more conditions or based on one or more probabilities. Conditions can be based on attribute values, variable values, entity types, or expressions. We chose to use the N-way by chance, based upon the ratio of distribution derived from the statistics supplied by the Hospital.

Resource	ICU type	Process time distribution
Resource 1	NICU	Triangular (1,3,12)
Resource 2	MICU	Triangular (1,4,15)
Resource 3	BICU	Triangular (1,3.5,16)
Resource 4	SICU	Triangular (1,3,14)
Resource 5	CCU	Triangular (1,3,9)
Resource 6	CTICU	Triangular (1,2,12)

Table 1. Representation of resources

The *Process Module* is the main processing method in the simulation. Options for seizing and releasing resource constraints are available. Additionally, there is an option to use a sub-model and specify a hierarchical logic. The process time is allocated to the entity and the categories of entities include: being value-added, being non-value-added, transfering, waiting, and other. The associated cost is assgined to the respetive category.

Resources represent the various ICU types as shown in Table 1. Each resource is a function with its own parameters. The capacity of each resource is fixed according to the number of beds that it has. The hourly number of beds that are busy was obtained from the Hospital. The last column of Table 1 shows the process time distribution of each resource, that is, each ICU type.

The Record Module is used to collect statistics in the simulation model. Various types of observational statistics such as count types, tallies and counter sets are available. The Dispose Module is the ending point for entities in a simulation model. Statistics on discharge of patients are recorded before entities are disposed.

A couple of assumptions are made in the simulation model. First, patients are assumed to stay in the same type of ICU, since only a few patients are moved from one type of ICU to another. Second, machine downtimes are assumed to be zero, since similar machines are set up in ICUs and they can be shared between ICUs.

4. Results

In the simulation model, entities are patients that utilize resources. Entity flow is the flow of patients into and out of ICUs. The simulation results presented below are a collection from 100 independent replications over a period of 365 days. The warm-up period was set for the simulation run to eliminate any bias at the early stages of the process (Law and Kelton, 2000).

In the simulation runs for the period of 365 days, the Hospital admitted 342 patients on average into ICUs, while it discharged 336 patients on average, and patients stayed in TCUs 6.1873 days on average. The actual data obtained from the Hospital, for example, show that 388 patients were admitted into ICUs in 2005 on average.

Table 2 shows the total process time per patient by ICU types, and Table 3 shows the average number of patients admitted into and discharged from each type of ICU in a year. The minimum and maximum average numbers indicate the limits for the 95% confidence intervals that are possible within the given parameters of the model.

ICU Type	Avg	Min avg	Max avg
BICU	7.2360	5.7458	10.2682
CCU	4.1316	3.6953	4.8025
CTICU	7.6603	6.6592	8.8359
MICU	6.7344	5.9345	7.1486
NICU	7.9872	7.5093	8.4093
SICU	5.8598	4.9443	6.6317

Table 2. Total process time per entity

ICU type	Number of entities entering each process			Number of entities leaving each process		
	Avg	Min avg	Max avg	Avg	Min avg	Max avg
BICU	8	2	11	8	2	11
CCU	64	54	73	63	53	73
CTICU	104	84	124	102	83	120
MICU	33	22	41	32	22	40
NICU	69	53	79	67	52	75
SICU	65	53	82	65	53	81

Table 3. Number of entities entering and leaving each process

ICU type	Simulated average (yearly basis)	Actual average (monthly basis)	Min avg usage	Max avg usage
BICU	0.595	0.604	0.000	1.484
CCU	4.180	5.480	4.124	6.168
CTICU	8.759	8.772	3.757	12.852
MICU	3.854	2.652	1.200	4.608
NICU	4.458	6.312	3.336	11.800
SICU	4.914	5.690	3.460	7.390

Table 4. Average bed usage

Table 4 shows the actual usage of beds per month on average in 2005 and the simulated usage of beds for the simulation period of 365 days. A discrepancy is found between the actual values and the simulated results and this may be due to the difference in time duration (monthly versus yearly). However, this discrepancy is within the tolerance limit (95% confidence interval), which can validate the simulation model.

ICU type	Avg number of beds recommended	Actual (existing) number of beds
BICU	4	4
CCU	5	8
CTICU	9	17
MICU	4	8
NICU	5	8
SICU	5	10
Total	32	55
Recommended	46	-

Table 5. Number of beds recommended (rounded to whole numbers)

The total number of beds occupied can be calculated by adding the total numbers of beds occupied in each ICU, as shown Table 5. However, it should be noted that there is no difference between the actual and recommended numbers of beds in the BICU, since the BICU is a specialized ICU with a different setup. The recommended number of beds for each ICU type is in accordance with the 70% occupancy rate as prescribed by most intensive care societies (The Intensive Care Society, 2003).

5. Centralization Process

The centralization process started with identification of auxiliary rooms required to compliment the normal operations of ICUs, followed by examination of the existing floor space. Then, recommendations were made so that the Hospital could have clusters of ICUs within the proposed site rather than one single area housing all beds. The following design factors were considered in setting up the centralized ICU.

Site Selection: The ICU should always be at a place where it is accessible to the departments from which patients are usually admitted, such as the accident and emergency department, recovery room, and surgical and medical wards. It is also desirable to locate the ICU close to the imaging department. The proposed site in Block 2 Level 2 at the Hospital fits the requirements perfectly. The operation theatres are just next to it. Most importantly, the two largest ICUs, SICU and CTICU, are already sited there.

Size of the ICU: According to the standard practices in UK, where the sizes of ICUs vary from three to eighteen beds, ICUs with less than four beds are considered inefficient as it may not benefit from economies of scale. Further, ICUs with more than eight beds may pose problems for clinical management. A general recommendation is that ICUs should generally have 60-70% of bed occupancy on average. At the same time, ICUs ought to be able to handle 95% of all appropriate emergency referrals for admission. A number of mathematical models were studied to determine the optimal occupancy. Larger ICUs could maintain a higher level of occupancy, yet they still could accommodate unexpected referrals (The Intensive Care Society, 1997).

Due to the large numbers of ICUs required to serve the Hospital, it is proposed to divide them into separate clusters of eight to ten beds, but still locate them within the general area. The occupancy rates would be set at 70% as the ICU will be a large establishment with a large numbers of beds. The different clusters of beds will be able to share auxiliary facilities such as laundry rooms, storage rooms and so on.

Patient Area: Each bed should have at least 20m² floor area and 2.5 meters of unobstructed corridor space beyond the working area. The shape of each cubicle should be rectangular. This study proposes a bed to each cubicle and one cubicle in each cluster that is capable of accommodating two beds. Each cubicle will be able to accommodate any kind of patients who require intensive care, except for burns patients who require 'clean' rooms. The recommended size of each room is 20m² at minimum In the event that special equipment needs to be brought

in and the space is not sufficient, the patient can be transferred to a double cubicle.

Central Station/Nurses Station: The station must be sited where it is possible for the duty staff to have a clear and unobstructed view of the patient area. An ideal space area would be 10.5 meters by 15 meters.

Storage Room: The equipment storage room is used to keep large equipments such as drip stands and cardiac/respiratory equipments. An ideal size would be about 3 meters by 5 meters. Every cluster of ICUs is proposed to have its own storage room.

Soiled and Clean Utility Rooms: These rooms are used to store equipment, linens and procedure trays. Those in the soiled rooms are for cleaning, while those in the clean rooms are for usage. Every two clusters of ICUs are proposed to share a single soiled and clean utility room. The recommended size of the soiled utility room is 4 meters by 5 meters, while that of the clean utility room is 4 meters by 3 meters.

Staff Room: The staff room is where the staff rest during breaks. As much vigilance is required of the staff, the room will need to house kitchen facilities such as beverage bar, fridge and a proper resting place for the staff. An ideal area for it will be about 5 meters by 5 meters, although the recommended size by the Intensive Care Society is 3 meter^2 per two beds (The Intensive Care Society, 2003). This study recommends each cluster to have a staff room each.

Doctor's on-call Room/Study: This room is basically a rest room for doctors on duty. A recommended size would be 4 meters by 5 meters. Each cluster will have its own doctor's on-call room/study.

Miscellaneous: There are a myriad of other facilities such as satellite pharmacy, medical office, and cleaner's room, which the ICU needs. Because of space constraints, however, they will not be housed in the same area as the main ICU compound. Instead, they will be housed in an area adjacent to the main ICU compound. Facilities of this type include satellite pharmacy, medical office, consultant's office, reception area, receptionist's room, seminar rooms, tutorial rooms and cleaner's room.

5.1. Proposed Size of a Cluster of ICUs

As shown in Fig. 1, each ICU cluster would have eight beds and three to four auxiliary rooms. These clusters would be spread out over the proposed area at Block 2 Level 2. Each cluster would take up an area of 23.6 meters by 21.6 meters. The eight doors by the side are the entrances to each ICU. The size of each ICU will be 5 meters by 5 meters and the standard size of auxiliary rooms will be 4 meters by 4 meters.

5.2. Proposed Centralization Plan

It was proposed earlier that all existing resources should be torn down and cleared to make space for a whole new ICU centre. However, this would greatly affect the ICU capabilities of the Hospital. It would mean tearing down the CTICU and SICU, which in turn would eliminate twenty-seven beds, and so, it would not be an acceptable option for the Hospital.
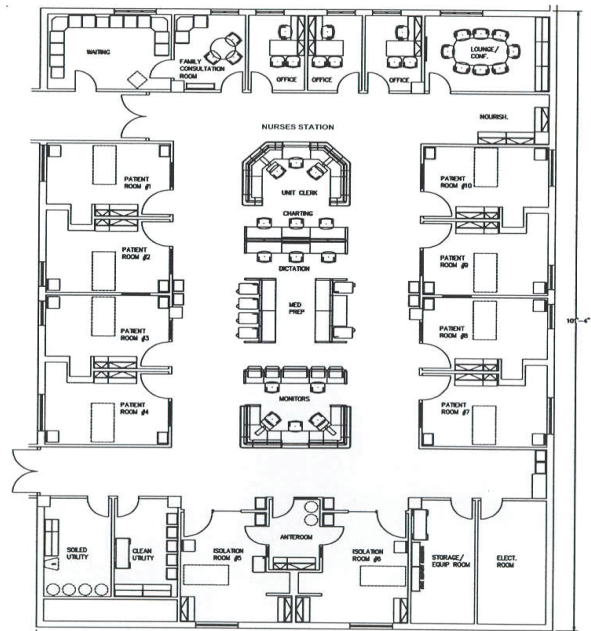

Fig. 1. Proposed design of a single cluster of ICU (nurses station)

After close examination of the floor plan and the optimum number of rooms, this study suggests that the Hospital keeps its CTICU and SICU, together with their auxiliary facilities. The optimum number of ICU beds is forty-six. Keeping the twenty-seven beds of SICU and CTICU means that nineteen new beds should be added. The floor space available for these nineteen beds is about 1,157m^2. The proposed area for each cluster is 510.3m^2. The floor space available is capable of accommodating two clusters. The additional three beds to the two clusters of eight beds would take a space of 136m^2. This is adequate as the recommended size of each ICU bed is about 20m^2.

Auxiliary facilities for the two clusters (total 8 rooms) include:

- 1 Clean utility room
- 1 Soiled utility room
- 1 Staff room
- 2 Storage rooms (one for each cluster)
- 2 Doctor study/ on-call rooms (one for each cluster)
- 1 Extra room (miscellaneous)

Thus, the proposed area is well suited for the centralization of all ICUs in the Hospital. It seems more feasible for the Hospital to keep its CTICU and SICU to prevent a disruption in day-to-day operations, rather than splitting all ICUs into clusters as proposed earlier. As a result, only two new clusters with nineteen beds in total will be constructed, instead of the proposed eight beds per cluster. However, this centralization plan does not include some auxiliary facilities for the two clusters. These facilities are not crucial to the operation of the ICU and can be sited at Block 5, which is connected to Block 2 by a link-way. Alternatively, these facilities could be shared with the auxiliary facilities of the existing CTICU and SICU.

6. Conclusion

This study attempted to propose a solution for centralization of ICUs at the Hospital. A simulation model

of admission of patients was developed to predict the flow of patients into ICUs and the occupancy rates of ICUs. The simulated results were found to be within the tolerance limits when compared to the actual occupancy rates.

We recommended the Hospital to have clusters of ICUs after deliberating through different models for a layout of the ICU. It seems that previous studies did not examine ICUs of the size and magnitude of the ICU proposed to the Hospital. Clusters of ICUs would also help lower the patient-to-nurse ratio, one of the primary goals of the ICU, and so, nurses would be able to monitor patients more closely.

It should also be noted that many auxiliary facilities are not within the recommended distances because of space constraints in the Hospital. However, facilities that are more crucial to the operation of the ICU were all to be sited around the ICU to minimize any disruption to operations.

The Hospital has a shortage of space and manpower that would not be alleviated in the short run. Further expansion of ICU facilities would be next to impossible without considering a decentralization process. Unless the Hospital does not foresee an expansion plan in the near future, it is recommended to put a hold on the plan for centralization of ICUs. It would be better to have a more spacious site, which is designed for the sole purpose of the centralized ICU with forty-six beds or more.

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