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A Task Assignment Rule for the Registered Nurses of the Emergency Department of Hospital Using Multiple System Attributes

Daebeom Kim[1†]

병원 응급실에서 여러 속성을 고려한 간호사 치료태스크 할당 규칙에 관한 연구

김대범

ABSTRACT

Overcrowding in an Emergency Department (ED) of hospital is a common phenomenon. To improve the service quality and system performance of the ED, a task assignment rule for the Registered Nurses (RNs) is proposed in this paper. At each task assignment point, the rule prioritizes all treatment requests based on the urgency which is determined by the multiple attributes such as accomplishment time of treatment task, elapsed time of treatment request, total remain time to patient discharge, and number of remain treatments. The values of partial urgency with a single criterion are determined and then overall urgency is computed to find the most urgent one among current requests with the importance weights assigned to the criteria. Through computer simulation, the performance of the proposed rule is compared with current rule in terms of the length of stay and system throughput in a simplified ED system of the hospital M.

Key words : Emergency department, Task assignment rule, Registered nurse, Urgency of treatment task

요 약

병원 응급실의 환자 과밀 현상이 점점 더 심해지고 있는 상황이다. 본 연구에서는 응급실의 치료 서비스 수준 및 시스템 효율을 개선하는 방안의 일환으로 간호사에게 치료 테스크를 할당하는 규칙을 개발하고자 한다. 제시하는 규칙에서는 매 치료 테스크 할당 시에 4개 속성 즉 1)태스크의 수행시간, 2)치료 요청 후의 흐른 시간, 3)모든 치료가 다 끝날 때까지의 총 남은 시간, 4)남은 치료단계의 개수를 동시에 고려한다. 각 치료 치료태스크의 기준별 긴급도를 계산하고, 기준별 중요도를 반영한 전체긴급도 값을 계산한 후 이 값이 가장 큰 태스크에 간호사를 할당한다. 컴퓨터 시뮬레이션을 통하여 M 병원 응급실의 간략화 모형을 대상으로 기존규칙과 비교실험을 수행하였다. 환자가 응급실에 머문 평균시간 및 단위시간 동안 처리한 환자 수를 평가기준으로 실험한 결과 제시한 규칙이 두 기준 모두에서 우수한 성능을 보였다.

주요어 : 응급실, 태스크 할당 규칙, 간호사, 치료태스크 긴급도

1. Introduction

Overcrowding of the Emergency Department (ED) of hospital is a common present situation. The growth of ED demands has not been solely due to the general increase of the patient population. Other growth factors have included the increased number of patients who do not have medical insurance and the increased number of elderly people. Almost half of U.S. hospitals have reported that their ED is at or over capacity. Overcrowding decreases the quality of health care and the efficiency of ED operations. Demand for EDs increased from 1995 to 2005, whereas supply of EDs decreased during the same period. It was estimated that 93.1 million patients visited EDs in 1995, and 114.8 million visited in 2005

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[1)] 강남대학교 산업시스템공학과
주 저 자 : 김대범
교신저자 : 김대범
E-mail; dbkim@kangnam.ac.kr

- approximately a 20 percent increase. At the same time, the supply of EDs decreased by 5 percent (4,884 in 1995, to 4,611 in 2005) (AHA, 2007). In addition, ED overcrowding affects the profitability of hospital since approximately 40 percent of all hospital charges come from ED patients (Evans and Unger, 1996). Therefore, it is critical to reduce the length of stay of patients in the ED for the improvement of ED processes because having patients wait is a non-value added activity for patients as well as hospitals.

ED overcrowding should be treated as a long term issue and policy changes such as financial assistance to hospital facilities and incentives for training ED staff resources should be considered (Schafermeyer and Asplin, 2003). Increasing the number of ED staff and beds and improving the efficiency of the ED process have been successful in dealing with the overcrowding of EDs (Schneider *et al*., 2001). The length of stay in the ED affects the satisfaction of ED patients (Boudreaux *et al*., 2004). The number of patients who leave without being seen by a physician in the ED is related to the duration of the stay of the patients (Brand *et al*., 2005). The predictability of patient arrivals at the ED is very important to allocating and scheduling ED staff. Times-series models tracking the relationship between the number of visits and the length of time have been found to be statistically significant (Champion *et al*., 2007). Time-series methods have also been used to assess the process of ED flow and the efficiency of ED process intervals; main ED process intervals between triage and patient discharge have been calculated and administrative intervention has been shown to be effective in reducing the length of stays (Kyriacou *et al*., 1999). The number of ED patient arrivals has been analyzed using a large amount of patient data from 2000 to 2003 for Richmond area hospitals. Hourly, daily, and event trends of patient load were analyzed in this research. For example, (i) ED patient arrivals began to increase at 9:00 in the morning, (ii) a high number of ED patients arrived on Mondays, and (iii) inclement weather, such as snowfall or a hurricane, also affected the number of ED patient arrivals. ED patient arrivals are affected by sport activities in the community, Thanksgiving Day and other holidays, paydays, or special community events such as the Homecoming Day of a local school or college (Tawney, 2005). The number of patient arrivals fluctuates by season. A linear regression forecasting model was proposed to predict Monthly ED patient arrivals (Park *et al*., 2008)

Simulation modeling has been used to identify the delay area of ED process and improve it. Kolb *et al*. (2007) analyzed the relationship between ED overcrowding and inpatient unit capacity where the assumption was that the main cause of ED crowding is the number of ED patients with high severity levels and the inpatient unit capacity. It was shown that ED overcrowding is closely related with inpatient unit utilization. Centeno and Ismail (2003) used a combined simulation method and linear programming to minimize the number of ED staff. Other simulation studies have applied Six Sigma principles to improve the ED process in the simulation model (Miller *et al*., 2003) and a simulation model of each ED process to analyze patient flows in ED and reduce the length of stay in ED has also been establish (Takakuwa and Shiozaki, 2004; Samaha *et al*., 2003; White, 2005). Park *et al*. (2008) presented a forecasting and simulation model for resource management of the hospital's ED. The key resources are triage nurses, patient beds, registered nurses, and medical doctors. Acuity degree of patient arrived at the ED is evaluated by a triage nurse. After assessment by a triage nurse, a patient waits for ED treatment by ED staff if ED beds, registered nurses or medical doctors are not available. The near future load level of each resource was presented using the proposed models.

In the ED system operation, the First Come-First Served (FCFS) basis rule is usually accepted because the patients of ED do not want be delayed or interrupted by the patients arrived later. It is known that the patients of triage and patient bed assignment stage are more sensitive to the FCFS rule than the patients assigned to the patient beds. The FCFS rule is not the best policy in the system performances such as average length of stay of patients and total number of patients completed and discharged a unit time-period. Kim (2009) presented a job assignment algorithm for the medical doctors of ED. The algorithm prioritizes all treatment requests based on the fuzzy urgency which is determined by the fuzzy multi-criteria decision-making method. It gives more flexible and adaptable operation of ED, but much computational burden is required.

This paper proposes a new task assignment rule for the Registered Nurses (RNs) of ED to improve the average length of stay of patients and system throughput. Each ED patient is served with the sequenced set of various and complicated treatment tasks on the patient bed. All treatment requests are prioritized based on urgency determined by the following four system attributes: 1) accomplishment time of treatment task (to increase the RN availability) 2) duration of patient waiting time (to reduce the waiting time of patients) 3) total remain time to patient discharge (to increase the availability of patient beds) and 4) number of remain treatments (to reduce the waiting time and dissatisfaction of ED patients with small number of RNs' treatments). The urgency for each treatment request is calculated separately at RNs initiated task assignment decision point.

The rest of this paper is organized as follows. The structure of the proposed rule is presented. Through computer simulation studies, performance of the rule is compared with that of the current task assignment rule. Finally, conclusion appears in last section.

2. Development of Task Assignment Rule for the Registered Nurse

2.1 System Situation

The ED is a hospital facility for the provision of unscheduled outpatient services to patients whose conditions require immediate care and it is staffed 24 hours a day, 7 days a week. A hospital is currently experience ing an overcrowding of ED patients. Overcrowding of EDs may lead to treatment delays for ED patients, which results in ED patients having to spend longer wait times to see medical staffs such as Medical doctors (MD), RN and Supporting Physicians (SP). Overcrowding of the ED decreases the quality of healthcare and the satisfaction of ED patients, and it is related to the percentage of patients who leave without seeing ED staffs.

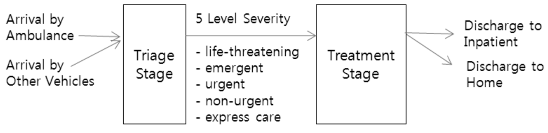

Fig. 1. The ED process of hospital

Fig. 1 shows the ED process of hospital. Patients usually arrive at an ED by ambulance or by their private vehicles, although a small percentage of total ED patients is transferred from other hospitals. Patients arriving at an ED are evaluated by triage stage. Evaluations in triage are usually handled by a nurse. At this stage, the emergency severity conditions of patients are evaluated and categorized using a five-level severity index as follows: life-threatening; emergent; urgent; non-urgent; and express care. After assessment by a triage nurse, a patient waits for ED treatment by ED staff if ED beds, nurses or medical doctors are not available. Some patients are admitted to hospital inpatient beds if further medical treatment is required. If the hospital has an inpatient bed available, patients are discharged to inpatient beds from the ED. Otherwise, patients remain in an ED room until inpatient beds are made available to them. The ED of hospital operates with a fixed number of staff and beds. The number of ED staff is scheduled in advance with little flexibility, whereas patients arrive at separate points in time with a great deal of ebb and flow.

There are two types of task assignment rules for the RNs such as “NR initiated task assignment rule” and “patient initiated task assignment rule”. At least one component of each class of rules must be present in the system in order to make task assignment decisions. NR initiated task assignment rule is invoked whenever a RN completes a treatment task and is to be reassigned to another task. On the other hand, patient initiated task assignment rules is invoked whenever a patient makes a request and two or more idle RNs are available.

2.2 Framework of the rule

Considering multiple system attributes, a new RNs' task assignment rule is proposed for more adaptable operation of ED. Four task assignment criteria are considered: accomplishment time of treatment, elapsed time of treatment, remain time to patient discharge, and number of remain treatments. In order to meaningfully aggregate the evaluation results from these criteria of different semantic dimensions, the outcome obtained by each criterion needs to be converted to a dimensionless index. In this study, the urgency measure of treatment requests is introduced to assess their priorities. First to be defined are the partial urgency functions for each task assignment criterion. The values of the importance weights are also qualitatively assigned by the decision maker considering the decision-making environment. At a task assignment point for each treatment request, the values of partial urgency (i.e. urgency with a single criterion) are determined according to partial urgency functions. Finally, the overall urgency is computed to find the most urgent one among current requests with the importance weights assigned to the criteria.

2.3 Calculating the partial urgency

We calculate the partial urgency, i.e. the urgency of a treatment request for each of the following four criteria.

2.3.1 accomplishment time criterion

To increase the RN availability, the accomplishment time of treatment task is considered as follows.

Let, i : treatment request index, $i=1,2,\cdots,I$

t : time at which task assignment decision is made

s_i : setup time for the treatment request i[time]

p_i : processing time for the i[time]

d_i : travel time from nursing center of RNs to the patient bed associated with request i[time]

T_i : accomplishment time of treatment request i $= s_i + p_i + 2d_i$

$\overline{T}$: average accomplishment time for the previous treatments satisfied

σ_T : standard deviation of accomplishment time for the previous treatments satisfied

$U_{1,i}$: partial urgency for treatment request i with accomplishment time criterion

$$= \begin{cases} 1-\dfrac{T_i}{\overline{T}+2\sigma_T} & T_i \le \overline{T}+2\sigma_T \\ 0 & otherwise \end{cases} \tag{1}$$

A treatment request has higher urgency if the accomplishment time is smaller.

2.3.2 Elapsed time criterion

The elapsed time of a treatment request at the patient bed is the amount of waiting time until the current task assignment decision point. Introduction of this criterion reduces the time interval between the placing of a treatment request and its fulfillment.

Let, E_i : the time treatment request i appears at patient bed

$\overline{E}$: average elapsed time for the previous treatment requests satisfied

σ_E : standard deviation of elapsed time for the previous treatment requests satisfied

$U_{2,i}$: partial urgency for treatment request i with elapsed time criterion

$$= \begin{cases} \dfrac{t-E_i}{\overline{E}+2\sigma_E} & t-E_i \le \overline{E}+2\sigma_E \\ 1 & otherwise \end{cases} \tag{2}$$

A treatment request has higher urgency if the elapsed time duration is larger.

2.3.3 Remain time criterion

The remain time criterion is adopted to increase the number of empty beds for the ED patients.

Let, R_i= total remain time until departure of patient associated with treatment request i

$\overline{R}$: average time duration to complete all treatment activities of each patient for the previous patients satisfied.

σ_R : standard deviation of time duration to complete all treatment activities of each patient for the previous patients satisfied.

$U_{3,i}$: partial urgency for treatment request i with remain time criterion

$$= \begin{cases} 1-\dfrac{R_i}{\overline{R}+2\sigma_R} & R_i \le \overline{R}+2\sigma_R \\ 0 & otherwise \end{cases} \tag{3}$$

A treatment request has higher urgency if the remain time duration is smaller.

2.3.4 Number of remain treatments criterion

To reduce the waiting time and dissatisfaction of ED patients with small number of RNs' treatments, the number of remain treatments is also considered as a criterion for task assignment.

Let, N_i= total number of remain treatments of patient associated with treatment request *i*

$\overline{N}$: average number of treatments of each patient for the previous patients satisfied.

σ_N : standard deviation number of treatments of each patient for the previous patients satisfied.

$U_{4,i}$: partial urgency for treatment request *i* with number of remain treatments criterion

$$= \begin{cases} 1-\dfrac{N_i}{\overline{N}+2\sigma_N} & N_i \le \overline{N}+2\sigma_N \\ 0 & otherwise \end{cases} \quad (4)$$

A treatment request has higher urgency if the number of remain treatments is smaller.

2.4 Calculating the overall urgency and ranking

Once all the partial urgency of a treatment request are obtained, the overall urgency of a treatment request is determined as follow.

$$U_i = \sum_{j=1}^{4} W_j U_{j,i} \quad (5)$$

where,

U_i : overall urgency of treatment request *i*

j : assignment criterion, $j=1, \ldots ,4$

$U_{n,i}$: partial urgency of a treatment request *i* with criterion *j*, $0 \le U_{j,i} \le 1$

W_j : importance weight given to the criterion *j*, $0 \le W_j \le 1$

It is assumed that the decision maker uses a set of values $W=\{W_1, W_2, W_3, W_4\}$ for importance weight. The importance weight W_j does not normalized to the sum is 1 because the meaning of its value is retained. For example, W_1=0.95 and W_2 =0.2 mean that the criterion C_1 is "very important" and C_2 is "unimportant". A treatment request with a higher U_i is ranked higher than one with a lower U_i.

2.5 Stepwise description of the rule

Now, the rule steps for RN's task assignment based on urgency are presented.

Step 1: Select the appropriate importance weight (W_j) for the task assignment criteria: accomplishment time, elapsed time, remain time, and number of remain treatments.

Step 2: At a task assignment decision point *t*, identify task assignment request list which contains all treatment requests. If there are treatment requests of the life-threatening patient, assign RN to the life-threatening patient and stop.

Step 3: If there are emergent treatment requests needed immediate action, assign RN to the emergent patient and stop.

Step 4: Calculate the partial urgency $U_{j,i}$ with respect to each criterion.

Step 5: Calculate the aggregated overall urgency U_i for each request based on $U_{j,i}$ and W_j.

Step 6: Select the request with the highest urgency value and assign to the RN

Step 7: Repeat steps 2 to 6 at every task assignment decision point.

2.6 A numerical example

The computational process of the proposed rule is demonstrated.

Let C_1 be accomplishment time of treatment request criterion, C_2 elapsed time criterion, C_3 remain time criterion and C_4 number of remain treatments criterion. Suppose the ED manager decided the appropriate importance weight (W_j)of each task assignment criterion C_j as follows; W_1=0.6, W_2=1.0, W_3=0.4, and W_4=0.7.

The manager finds that three alternative treatment requests A_1, A_2 and A_3 exist at a task assignment decision point.

The partial urgency $U_{j,i}$ is determined with equation

(1), (2), (3), (4), and possible outcomes are:

$U_{1,1}= 0.1,\ U_{2,1}= 0.9,\ U_{3,1}= 0.0,\ U_{4,1}= 0.3$

$U_{1,2}= 0.5,\ U_{2,2}= 0.0,\ U_{3,2}= 0.0,\ U_{4,2}= 0.1$

$U_{1,3}= 0.5,\ U_{2,3}= 0.4,\ U_{3,3}= 1.0,\ U_{4,3}= 0.2$

Using equation (5), each alternative's overall urgency U_i becomes:

$U_i = 0.6\times0.1+1.0\times0.9+0.4\times0.0+0.7\times0.3=1.19$

$U_2 = 0.47 \quad U_3 = 1.34$

The ranking order of urgency for the three alternatives is $U_3>U_1>U_2$. Therefore, the treatment request A_3 is assigned to the RN.

3. Evaluation of the Rule

3.1 Experimental conditions and assumptions

Fig. 2 shows the simplified ED layout of the hospital M studied in this paper. There are no capacity restrictions on the patient arrival area. The maximum number of patients allowed in the patient bed area is set to the total number of patient beds. There are four types of resources at the ED: medical doctors, patient beds, registered nurses, and triage nurses or physician assistants. The system is monitored by central computer to which the information related to patients, RNs, medical doctors, and patient beds are transmitted.

The ED processes are subject to random arrivals of ED patients that varied from hour to hour. There are two types of arrival of ED patients: patients usually arrive at ED by their own vehicles or by ambulance. Acuity degree of patient arrived at the ED is evaluated by a triage nurse. Patients wait to obtain triage assessment if a triage nurse is occupied with another patient. After assessment by a triage nurse, a patient waits for ED treatment by ED staff if ED beds, nurses or medical doctors are not available. Some patients leave ED after triage assessment if they believe they cannot wait for ED treatment.

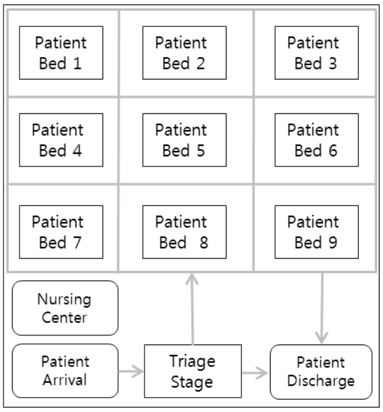

Fig. 2. Simplified ED layout of the hospital M

After completion of ED treatments, patients are discharged to home if medical doctors decide patients do not need any further treatment. However, some patients are admitted to the hospital if the physicians decide they need further treatments. Patients admitted as hospital inpatients wait in the ED if hospital beds are not available for them. ED staff requests hospital beds for the admitted patients and then assign hospital beds if hospital beds are available. In this case, patients still occupy nurse and ED bed resources until they are moved into the hospital by ED staff.

The RN accomplishes firstly setup operations of the selected task and then treatment operation. If a RN is idle and there is no treatment request, the RN returns to the nursing center and dwells until new treatment requests are available.

To reduce the computational time to perform the experimental studies, some simplifying assumptions are made. These assumptions together with some other operational polices and attributes are as follows.

1) The patients of triage stage are served on First Come First Service (FCFS) basis. Patients are also assigned to the patient beds on the FCFS base.
2) Upon the completion of task at patient bed, if nurse becomes idle, the ‘patient initiated task assignment’ rule is invoked. FCFS rule is used in the selection of RN.
3) Patients of ED arrive with Poisson distribution process, Poisson (λ), λ= 3~20 per hour. The mean number of patients per hour, λ, is varied according to the system conditions such as severe congested situation, congested situation, usual situation, idle situation, and very idle situation.
4) Acuity percentages are that Private vehicle: Life-threat-0.3%/Emergent-1.07%/Urgent-50%/Non-ur

Table 1. Input data for simulation model

Input data	Description
Patient arrival type	Arrival by private vehicle: 70 % Arrival by ambulance: 30%.
Triage duration	Triangular distribution Min=3 (min), Mode= 12 (min), Max= 20 (min), Triangular (3, 12, 20)
Number of treatment steps	Uniform distribution, Uniform (1,5)
Percentage of leaving without being seen at each stage	Percentage of leaving at pre-triage and post-triage: 5%
Treatment duration by Registered Nurse	Triangular (5,20,100) (min)
Percentage of patients admitted to hospital	Arrival by Ambulance/by Private vehicle: 47%/20%
Percentage of waiting for inpatient bed	Percentage of waiting or inpatient bed: 15%
Duration between inpatient bed request and bed assignment	Weibulll distribution, Weibulll (131, 0.707)

gent-29.3%/Express-care-9.7% and Ambulance: Life-threat-6%/Emergent-25%/Urgent-50%/Non-urgent-15%/Express-care-4%.

Table 1 shows the main attributes and input data studied in this paper. Table 2 shows the input data and calculating formula for the partial urgency $U_{j,i}$ and overall urgency U_i.

A discrete simulation model was programmed in FACTOR/AIM. At the development stage, FACTOR/AIM was also utilized to visualize the task assignment logic through animation. The simulation model was validated with pilot simulations.

Table 2. Calculating formular for $U_{j,i}$ and U_i

$U_{j,i}$	Description
$U_{1,i}$	s_i : Uniform (5,10) (min) p_i : Triangular (5,20,100) (min) d_i : Uniform (0.5, 1.0) (min) T_i : $s_i + p_i + 2d_i$ $\overline{T}=\sum_{k=1}^{K} T_{i,k}$, where $T_{i,k}$ is the k^{th} T_i and k is the serial number of assignment decisions completed, k=1,2...,K $\sigma_T=\sqrt{\sum_{k=1}^{K}(T_{.,k}-\overline{T})^2/K}$
$U_{2,i}$	E_i=decision point t-request time for treatment activity $\overline{E}=\sum_{k=1}^{K} E_{i,k}$, where $E_{i,k}$ is the k^{th} E_i $\sigma_E=\sqrt{\sum_{k=1}^{K}(E_{.,k}-\overline{E})^2/K}$
$U_{3,i}$	R_i= Averager processing time of the remain treatment steps at decision point t $\overline{R}=\sum_{k=1}^{K} F_{i,k}$, where $F_{i,k}$ is the k^{th} F_i, F_i is the total treatment time of the patients completed their all treatment steps $\sigma_R=\sqrt{\sum_{k=1}^{K}(F_{.,k}-\overline{R})^2/K}$
$U_{4,i}$	N_i=(total number treatment steps)-(number of remain steps) $\overline{N}=\sum_{k=1}^{K} N_{i,k}$, where $N_{i,k}$ is the k^{th} N_i $\sigma_N=\sqrt{\sum_{k=1}^{K}(N_{.,k}-\overline{N})^2/K}$
W	$W=\{W_1,W_2,W_3,W_4\}=\{0.95,\ 0.95,\ 0.95,\ 0.95\}$ for all decision point

3.2 Performance evaluation

The performance of the proposed rule is compared with current rule, First Come-First Serve rule (FCFS). Under FCFS, RNs are assigned to the treatment tasks sequentially in chronological order as requests for RN are received from patient beds or predetermined time by their previous treatment. The rule proposed in this paper will be called PROPOSED hereafter.

The average length of stay of patients (ALSP), and system throughput (SYST) were adopted as the major evaluation criteria of service quality and system performance. The length of stay of a patient begins when a patient arrives at ED and ends when he (she) is discharged from ED. System throughput is defined as the total number of patients completed and discharged from the ED during a unit period of time.

The results of the simulation experiments were obtained with 25 replications per alternative at each level of the experimental condition. Each replication was observed over one unit time (2 weeks) at steady state. The performance of the proposed rule was studied under various capacity of the RN resource. Considering the degree of bottleneck of RN in the system, 5 capacity levels were designed such as 1)severe bottleneck situation, 2)

Table 3. Results of ALSP and SYST

Rule	Level of RNs	Avg. Length of Stay (min)		System Throughput per day	
		Avg.	Std.	Avg.	Std.
FCFS	1	218.84	3.98	125.58	4.45
	2	153.74	5.69	161.88	5.62
	3	115.33	6.99	219.90	5.50
	4	102.77	7.56	254.63	7.03
	5	95.36	3.78	258.07	7.73
PROPOSED	1	157.73	8.10	176.52	4.90
	2	117.61	4.37	236.62	7.30
	3	93.06	7.31	257.76	6.80
	4	88.32	4.29	269.02	6.73
	5	85.32	4.19	263.98	5.58

bottleneck situation, 3)usual situation, 4)idle situation, and 5)very idle situation. Through pilot simulation, experimental levels of RNs were set as follows; level 1: 2 nurses, level 2: 3 nurses, level 3: 4 nurses, level 4: 5 nurses, and level 5: 7 nurses.

Table 3 contains the results of the simulation experiments with five replications per rule at each level of RNs. The table entries are the average (Avg.) and standard deviation (Std.) of the average length of stay and system throughput.

To analyze the relative performance of ALSP, equality of sample mean was tested via the method of the analysis of variance. General Linear Model Procedure of SAS, a statistical analysis package, was used and the following hypothesis was tested.

$$H_0: \mu_{FCFS} = \mu_{PROPOSED}$$
$$H_1: \text{Not } H_0 \quad (6)$$
where μ_i : mean of rule i

At the test level of α =0.05 and degrees of freedom of 1 and 248, the computed F-statistic of 35.78 and p-value of 0.0001 was significant. This indicates the means of ALSP of the two rules are not the same. Through Duncan's Multiple Range Test, it was subsequently established that the ALSP for PROPOSED rule gives higher performance than current FCFS rule. At the test level of α =0.05, the means of the two comparison rules were not grouped with the same letter of Duncan Group. Duncan Group A for the PROPOSED rule and Group B for the FCFS rule was significant.

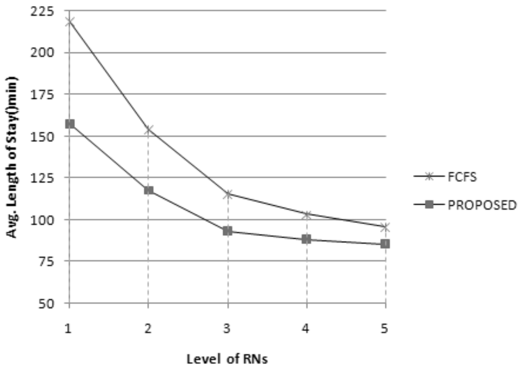

Fig. 3. Average length of stay under various level of RNs

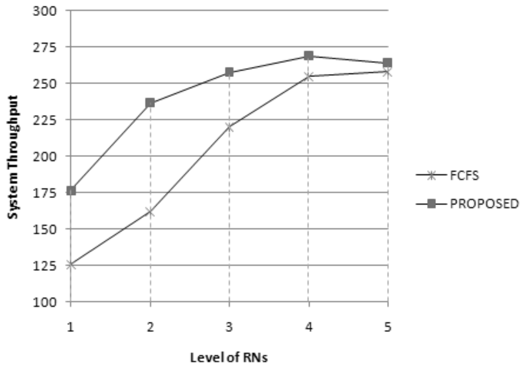

Fig. 4. System throughput under various level of RNs

The Fig. 3 visualizes the results of average length of stay of Table 3. The proposed rule outperforms the other rule, especially with a less number of RNs. With usual situation (level 3) of RNs, approximately 19.3% decrease in average length of stay was achieved by the PROPOSED rule over the FCFS rule. The figure shows that the improvement is decreasing as the number of RNs increases. If the ED has more RNs than needed, idle RNs tend to appear. In this case, discriminating power among task assignment rules disappear as depicted in the figure.

Using equation (6), the equality of two sample means of SYST was also tested. At the test level of α =0.05 and degrees of freedom of 1 and 248, the computed F-statistic of 42.32 and p-value of 0.0001 was significant.

The graphical result of SYST are shown in Fig. 4. It can be seen that the performance of the proposed rule shows substantial improvements in system throughput. With bottleneck condition (level 2) and usual condition (level 3) of RNs, approximately 46.2% and 17.2% increase respectively in throughput were achieved. There is no improvement in the very idle situation (level 5) of RNs. In the level 5 condition, whenever a treatment is requested, two or more idle RNs are available. It makes no difference between two rules on the performance.

4. Conclusion

In this paper, a task assignment rule of RNs was presented for the emergency department of hospital. The comparative study was carried out by simulation experiments in terms of the average length of stay of patients and the system throughput. In all the cases, the proposed rule was shown to perform substantially better than the other rule. This result shows that the quality level and the efficiency of overcrowding ED can be improved by changing the operation policy of RN resource. Although the results presented in this paper should be interpreted with reference to the simplified experiment conditions described earlier, it is believed that the demonstrated advantages may be quite general.

Further researches are needed on the issues of how to determine the importance weights for the criteria in response to the decision making circumstances and how to control the importance weight values to enhance the system performance.

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김 대 범 (dbkim@kangnam.ac.kr)
1989 고려대학교 산업공학과 졸업(학사)
1991 KAIST 산업공학과 졸업(석사)
1995 KAIST 산업공학과 졸업(박사)
1995～1999 삼성SDS(주) 책임연구원
1999～현재 강남대학교 부교수

관심분야 : 생산 및 물류시스템, 시뮬레이션, IT/IS