International Journal of Management Science
Vol 17, No 1, May 2011

A Knowledge Workers Acquisition Problem under Expanding and Volatile Demand: An Application of the Korean Information Security Service Industry*

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(Received: December 1, 2010 / Revised: March 7, 2011 / Accepted: March 10, 2011)

ABSTRACT

The aim of this paper is to consider the process of supplying trained workers with knowledge and skills for upcoming business opportunities and the process of training apprentices to be prepared to meet future demands in an IT service firm. As the demand for new workers fluctuates, a firm should employ a buffer workforce such as apprentices or interns. However, as a result of rapid business development, the capacity of the buffer may be exceeded, thus requiring the company to recruit skilled workers from outside the firm. Therefore, it is important for a firm to map out a strategy for manpower planning so as to fulfill the demands of new business and minimize the operation costs related to training apprentices and recruiting experienced workers. First, this paper analyzes the supply and demand of workers for the IT service in a knowledge-intensive field. It then presents optimal human resource planning strategies via the familiar method of stochastic process. Also, we illustrate that our model is applied to the human resource planning of an information security service firm in South Korea.

Keywords: Queueing, Simulation, Human resources, Optimization

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* This work was supported by the National Research Foundation of Korea (NRF) Grant funded by the Korean Government (MEST) (KRF-2009-32A-B00046).

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1. Introduction

Suppose that you are a human resources (HR) manager at an IT service firm in the following situation: a new IT service is emerging that is certain to have a profitable market and is expected to grow continuously in coming years; however, since it is in the emerging stage, the future demand for the IT service will fluctuate considerably until the market matures. Moreover, retaining skilled workers who specialize in a given service at the right time is a key success factor for winning a project opportunity. If the firm does not have enough experienced workers before the kickoff of a new project, they are likely to lose a business opportunity. Considering the volatile demand for skilled workers, the firm can hire apprentices and train them in advance. However, a surplus workforce leads to unnecessary holding costs. On the other hand, IT companies can choose to recruit skilled workers as needed. In this case, they pay a heavy price for hiring and retaining experienced workers. Eventually, for the acquisition of skilled workers, it becomes important for such firms to design an optimal combination of hiring and training apprentices in advance and recruiting experts in a timely manner. This would be reminiscent of a well-known managerial problem in supply chain management (SCM), "Make or Buy?" Cappelli (2008a, 2008b) suggested qualitative approaches to address uncertainties on supply and demand sides in human resource management (HRM).

The stochastic characteristics of the supply and demand of a workforce are considered in this paper. Furthermore, a human resource strategy capable of minimizing the operation costs related to the hiring and training of workers is analyzed here. Cost factors such as the hiring cost and the training cost, and the elasticity of the supply of experienced workers in the labor market have an impact on the retention rate of apprentices by such businesses. If the demand for a workforce is volatile, recruiting skilled workers in a timely manner is more profitable when coping with an upcoming IT project. This paper presents a quantitative model for the described managerial problem of determining an optimal mix of internally training unskilled workers in advance and externally acquiring skilled workers in a timely fashion under uncertain expanding demand. We utilize a queueing model for the analysis of the "Train or Recruit" problem to capture the stochastic characteristics of the supply and demand of skilled workers for the service. Through the model, we derive optimal strategies under various demand characteristics and cost structures. These results provide theoretical insight into the problem and are expected to be helpful in making optimal decisions in real, practical situations.

Numerous mathematical models have been introduced in human resource planning over the last half century. Various modeling approaches in human resource planning can be found in the survey by Price *et al*. (1980) and in Purkiss (1981). In particular, Price *et al*. (1980) classified related research into two types of models. One type is a descriptive model that forecasts the results of various human resource policies in actual organizations. Markov models (Bartholomew, 1973; Grinold and Stanford, 1974), fractional flow models (Grinold, 1977) and renewal models (Bartholomew and Forbes, 1979) were applied in previous studies. The other type, known as a normative model, can be defined as a model that obtains a set of feasible solutions for the decisions related to workforce planning behavior. Linear programming (Grinold, 1977), goal programming (Price, 1978; Zanakis and Maret, 1981), stochastic programming (Martel and Price, 1981) and network methods (Grinold, 1976) have been used in the construction of normative manpower models. In addition, several investigations have recently extended this topic to analyze the effects that lead to changes in the manpower structure. De Feyter (2006) described the motives for a transition in an organization and classified the personnel system into more homogenous subgroups that were grouped by similar behavioral patterns. Anderson (2001a) analyzed the knowledge for works that yields to differences in the quality of workforces. Anderson (2001b) developed a staff planning policy under non-stationary demand. However, there is little research that considers the possibility that experienced workers can be acquired in a timely manner as if they are just-in-time (JIT) inventories in a supply chain management (SCM) scheme. IT companies are prepared to pay a premium for recruiting skilled workers so as not to lose business opportunities, such as IT projects. Hence, the model and analysis presented here, based on a normative approach, reflect a more realistic skilled workforce acquisition strategy compared to those of previous studies. Also, we demonstrate that our quantitative model can be applied to offer a guide for making optimal decisions in the workforce management of an information security service company in South Korea.

2. Problem Description

2.1 Workforce Demand

In an IT service firm, additional workers are needed when a new business opportunity arises or when current workers retire. New contracts to support other customers necessitate the hiring of additional apprentices or skilled workers if there is no surplus labor that can deal with the existing task. Also, vacant positions should be filled within a certain period of time.

2.2 Workforce Supply

Because IT technology evolves rapidly, it is critical for an IT service firm to train its workforce and retain its skilled/experienced workers. Generally, a company hires apprentices regularly and cultivates their technical skills. However, a sudden request for skilled workers makes necessary the acquisition of experts outside the firm, and such workers often demand higher pay.

In short, there are two alternatives. One is to hire a sufficiently large workforce and train the workers in anticipation of a time when they will be needed. The other is to recruit skilled workers in the time of need. The former calls for directing a considerable amount of the company's budget to employment while allowing it to respond to market expansion promptly. The latter could increase human resource management costs, while it could decrease the risk for losing a new project due to a shortage of manpower.

2.3 Objective Functions

In a situation where the IT service market is expanding and demand for skilled workers is increasing, the firm could design short-term HR policy to retain a surplus workforce such as apprentices or interns, rather than to consider the dynamics of workers who need to be reassigned to another project at the end of current projects. Also, a buffer workforce should be filled in order to be prepared for upcoming projects. This approach is the same as the safety stock in inventory theory. However, if the buffer is about to be exhausted, the firm should recruit skilled workers.

The problem is to minimize the operation costs related to hiring and training the workforce and lost cost. We consider the following cost factors:

- Lost cost: the cost that arises when a new business opportunity is lost due to a shortage of manpower;
- Holding cost: the cost of holding surplus manpower (buffer);
- Recruiting cost: the cost of hiring both apprentices and experienced workers (Obviously, the cost of hiring the experienced workers is higher than the cost of hiring apprentices).

Control variables that determine the total HR costs are the size of the buffer, similar to a safety stock, and the point of transition from hiring apprentices to recruiting trained workers. The latter has an advantage of a short interval between hiring and assigning the worker to a new project. On the other hand, a time-consuming on-the-job training (OJT) course will be needed for the apprentice.

3. Model Development and Analysis

3.1 Modeling

Demand can be considered as the arrival of work and supply for the workforce as service. The queueing analysis deals with a stochastic process made up of the customer's arrival and departure after the completion of a service. Hence, queueing theory is utilized for determining how to analyze the supply and demand in the workforce and designing the optimal HR planning.

Workforce demand is a Poisson process. A random size of new workforce is involved. Also, it is assumed that the time interval between acquiring necessary manpower and assigning a task has an exponential distribution. If the firm hires an apprentice to cope with an additional project, a low service rate could be assumed, while recruiting an expert could bring a high service rate. Also, we assume that projects are completed one by one since employment and dispatch could occur at different times and the service rate is not switched between high service rate and low service rate in the middle of service. The maximum buffer-the surplus labor-size is K. Thus, it could be considered as an $M^X / M^H, M^L / 1 / K$ queueing system.

The assumed cost factors are outlined in Table 1.

Table 1. Cost factors

Cost factor	Assumptions
Holding cost	A fixed cost c_H is incurred on any surplus worker during a unit time
Lost cost	If a demand cannot be fulfilled by the current amount of surplus workers, all the units of demand are lost (not partially accepted). A fixed cost c_L is incurred for each unit of demand lost.
Recruiting cost	A fixed cost c_{RE} is incurred each time an experienced worker is recruited and c_{RA} is incurred each time an apprentice is recruited.

3.2 System Size and Performance Measures

The notations in this paper are defined as follows:

K : Buffer size;
λ : Arrival (demand occurrence) rate;
G : Random variable of demand size, $\Pr(G = k) = g_k$;
μ_H : High service rate (hiring the experienced workers and assigning them to projects);
μ_L : Low service rate (hiring an apprentice and filling the buffer);
R : Buffer size at which service rate changes, ($1 \le R \le K$);
P_n : The steady state probability where the number of not-yet-assigned demands is n;
L : Mean system size (Expected number of vacancies in the workforce buffer).

Since the Poisson arrival and exponential service times are assumed, the steady state probabilities $\{P_n;\, 0 \le n \le K\}$ can be obtained from the global balance equations and normalization condition as follows (see Wolff, 1989):

$$n = 0: \qquad \lambda P_0 = \mu_L P_1 \tag{1.1}$$

$$1 \le n \le R-1: \qquad \lambda \sum_{k=1}^{n} P_{n-k} g_k + \mu_L P_{n+1} = (\lambda + \mu_L) P_n \tag{1.2}$$

$$n = R: \qquad \lambda \sum_{k=1}^{n} P_{n-k} g_k + \mu_H P_{n+1} = (\lambda + \mu_L) P_n \tag{1.3}$$

$$R+1 \le n \le K-1: \qquad \lambda \sum_{k=1}^{n} P_{n-k} g_k + \mu_H P_{n+1} = \left(\lambda + \mu_H\right) P_n \tag{1.4}$$

$$n = K: \qquad \lambda \sum_{k=1}^{n} P_{n-k} g_k = \mu_H P_n \tag{1.5}$$

and

$$\sum_{n=1}^{K} P_n = 1 \tag{2}$$

Solving the equation (1) and equation (2) simultaneously, which are simple linear equations of $(K+1)$ variables, gives the probabilities $\{P_n;\, 0 \le n \le K\}$. However, the equations of (1) are linearly dependent, one of them, for example, equation (1.5), should be substituted by equation (2).

Given $\{P_n;\, 0 \le n \le K\}$, the mean system size can be obtained as $L = \sum_{n=1}^{K} nP_n$. Since the service process corresponds to hiring surplus workers, the state K represents the state in which no surplus workers are present while the state 0 represents the state in which the maximum K surplus workers are present in the system. Thus, the expected number of surplus workers is $K-L$; hence, the expected holding cost during a unit time is determined by $c_H \cdot (K-L)$.

A demand is lost when the demand size exceeds the number of surplus workers present in the system. Since the Poisson arrival process is assumed, the probability, where the number of vacancies in the buffer being n when a demand occurs, is identical to the steady state probability P_n. Thus, the rate at which demands become lost due to exceeding buffer size K is stated as $\lambda \sum_{n=0}^{K} P_n \sum_{i=K-n+1}^{\infty} g_i$; hence, the expected lost cost is $c_L \cdot \lambda \sum_{n=0}^{K} P_n \sum_{i=K-n+1}^{\infty} i\, g_i$. Similarly, the rate at which experienced workers are recruited is $\mu_H \sum_{n=R}^{K} P_n$ while the rate at which apprentices are recruited is stated as $\mu_L \sum_{n=0}^{R-1} P_n$. Therefore, the expected total cost per a unit time can be finally expressed as

$$TC = c_H \cdot (K-L) + c_L \cdot \lambda \sum_{n=0}^{K} P_n \sum_{i=K-n+1}^{\infty} i g_i + c_{RE} \cdot \mu_H \sum_{n=R}^{K} P_n + c_{RA} \cdot \mu_L \sum_{n=1}^{R-1} P_n \tag{3}$$

3.3 Discussion of Optimal Strategies

Given the arrival and service rates and the cost factors, finding optimal strategies is merely searching for optimal combinations of the parameters K and R such that the total cost TC is minimized. Obviously, the maximum size K of surplus workers affects both the holding cost and the lost cost, and, therefore, the total cost. However, we will assume that K is fixed and will only see the impact of the threshold R on the total cost, in order to focus our discussion on the comparison between the two alternative strategies, "train or recruit," and their optimal mixture. Moreover, the maximum number of surplus workers is bound by the financial and managerial capacities of the firm, which remains constant over a period of time.

If R is equal to K, it means that the firm adopts a strategy in which all necessary workers are supplied from the internal training of apprentices. On the other hand, if R is equal to 0, the strategy is that all workers are supplied from the external recruitment of experienced workers. Thus, as R decreases to 0, the average service rate increases and there is an implied increase in recruiting cost. It also implies a low mean system size L and, therefore, a high holding cost. In contrast, as R increases to K, the average service rate decreases, leading to a high probability of the blocking of demands and, therefore, a high lost cost. As a consequence, there is a tradeoff between the holding and recruiting costs and the lost cost. In spite of great dependence on the supply and demand characteristics of knowledge workers, if the maximum size K of surplus workers is appropriately determined, the optimal values of R are likely to be between the two extreme values 0 and K. The following procedure shows the process of obtaining the optimal value of R, which guarantees the minimum total human resource cost.

- Step 0: Set $R = 1$.
- Step 1: Set up the equations corresponding to (1) and (2), and solve simultaneously.
- Step 2: Substitute the result of Step 1 into Equation (3) to determine the total cost, which corresponds to the specific R value.
- Step 3: If $R < K$, go to Step 4. Otherwise, if R is equal to K, this procedure ends. The minimum total cost and corresponding R value can be figured out by comparing the cost results of Step 2.
- Step 4: $R = R+1$ and go to Step 1.

In addition, we can analyze the effects of the volatility of demand and the difference in recruiting costs on the optimal human resource cost. Hence, we now state the following four hypotheses explicitly in terms of the parameter R:

- Under the same arrival and service rates and the same cost factors, as the volatility of demand size increases, the optimal value of R decreases;
- Under the same arrival and service rates and the same volatility of demand size, as the difference in recruiting costs of experienced workers and apprentice increases, the optimal value of R increases.
- Under the same arrival and service rates and the same volatility of demand size, as the holding cost for a surplus worker increases, the optimal value of R increases.
- Under the same arrival and service rates and the same volatility of demand size, as the lost cost for each unit of demand lost increases, the optimal value of R decreases.

The first hypothesis means that if future demands are volatile, the urgent acquisition of experienced workers is preferable to the usual acquisition of apprentices in advance. The second hypothesis means that if the firm has to pay a higher price for the urgent acquisition of experienced workers than the usual acquisition of apprentices, the usual acquisition of apprentices is more desirable. The third hypothesis means that if the firm has to pay a higher price for a surplus worker, the firm tends to hire apprentices rather than experienced workers. In addition, the fourth hypothesis means that if the firm has to pay a higher price for each unit of demand lost, the firm tends to prefer the urgent hiring of experienced workers to the hiring of apprentices. We will demonstrate numerical results in support of our hypotheses in the next section.

4. An Illustrative Example

4.1 Overview of an Information Security Service Firm in South Korea

In order to apply our model for the human resource management problem in a real world example, we considered an industry with the following features: 1) The industry is so knowledge intensive that retaining a skilled workforce that has knowledge and experience is a high priority. 2) Manpower is involved in time-bound projects to render knowledge service to customers within a contract period. Thus, demand for workforce depends on new project contracts. 3) The industry is currently on the rise, which guarantees constant demand for work for the time being. Table 2 shows that a security service industry has been continuously expanding and we assume a stationary increasing demand for security service workforces. We choose the information security service industry in South Korea, which fulfills the three assumptions of our model. It is difficult to estimate the demand for an information security service since the demand has been affected by instances of security breaches. Hence, it is also difficult to estimate when the security service will be needed, how many experts will be needed for a project, and what level of knowledge service will be required. Since the workforce that will consult for the information security service should retain the various knowledge and experience relating to the technical and/or managerial aspects of the security problems, it is difficult for the information security service company to determine the length of time to retain the experienced workforce.

Table 2. Total Sales of Korean Security Service Industry

Year	2004	2005	2006	2007	2008	2009
Total sales	59,824	86,859	83,608	99,996	133,062	143,616

Note) Unit of cost: 1,000 USD Source: Knowledge Information Security Industry Association (KISIA).

The ministry of knowledge economy in South Korea designates companies that can perform information security tasks such as analyzing the vulnerabilities in a network infrastructure and establishing countermeasures for security breaches as specialized information security service firms. Since the first designation in 2001, seven companies have been appointed as specialized security service firms as of October 2009: Secui.com, AhnLab, STG Security, A3 Security, Inzen, Lotte Data Communication, and Infosec. In our study, we asked six companies to complete our survey on human resource planning and received completed replies from four companies. The parameters necessary for applying our mathematical model were estimated based on the results of the survey. We now illustrate the application for analyzing the optimal workforce planning and test the two hypotheses mentioned earlier using an arbitrary security service firm.

4.2 Finding an Optimal Solution

We surveyed six security service firms in order to estimate cost factors, demand occurrence rate and the supply rate of the workforce. Table 3 shows the meanings and outcomes of the main parameters of our model.

Table 3. Estimation of Parameters

	results	survey questions
λ	2	Average number of new project contracts per month
G	5	Average number of workforce that are put in new projects
$1/\mu_H$	1/7	Average duration (months) from recruiting an experienced worker to putting him/her in the projects in order to fill the project members
$1/\mu_L$	1/3	Average duration (months) from hiring an apprentice to assigning him/her to projects after OJT
c_L	14,000	Average contribution rate of sales per manpower (average contract payment is divided by average number of project members)
c_H	6,000	Average holding cost of a worker per month
c_{RA}	2,000	Average cost incurred by recruiting and training an apprentice per month
c_{RE}	6,000	Average cost incurred by recruiting and training an expert per month

Note) Unit of cost: USD.

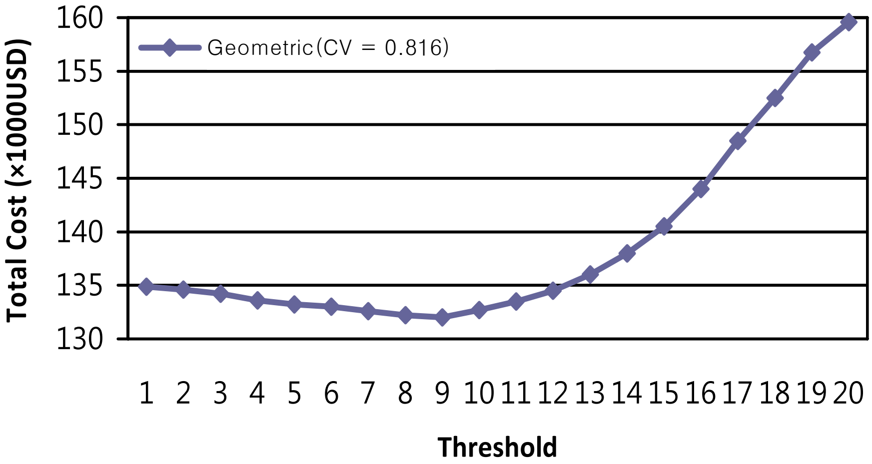

Figure 1. Optimal HR Cost Versus R

It is assumed that the workforce buffer size is fixed at 50 and that the probability of the buffer size, $\Pr(G = k) = g_k$, follows a geometric distribution. If the above parameters were inserted into Equation (3), we would get the threshold *R* which minimizes the human resource cost, *TC*, via the procedure explained previously. Figure 1 summarizes the various *R* and *TC*.

Based on the results of Figure 1, if *R* is 9, then the total cost of human resource planning is minimized. That is, in a case where the size of the workforce buffer, which consists of interns or apprentices, is fixed at 50, if the number of reserved workforce is less than 9, the security firm should hire experienced workers from outside the firm to avoid the loss of new projects as a result of a lack of project members. Note that the transition into hiring experts when *R* equals 9 enables the cost of human resource management to be minimized.

4.3 Hypothesis Test

In this subsection, numerical results based on the parameters of the survey described are applied for the testing of the hypotheses described previously. Every parameter described in Table 3 is still used. To examine the first hypothesis, two distributions are used for the batch size with different coefficients of variation (CV). They are the geometric distribution (CV = 0.89) and the negative binomial distribution (CV = 0.37), and each has a mean of 5, as determined by the survey results. Regarding the second hypothesis, two different cost structures are used. The first is that the cost of recruiting experienced workers is not as high and the second is that the cost is much higher than recruiting an apprentice. To be more specific, the average cost of recruiting experienced workers is changed as two following cases: Under $c_{RE} = 3,000$, recruiting experienced workers is relatively easy. Henceforth, this cost structure set is termed the 'Easy' set. The second is labeled the 'Hard' set, and c_{RE} is set at 6,000.

4.3.1 Effect of Volatility of Demand Size

Figure 2a and Figure 2b verify the first hypothesis. They show that the distribution with a larger CV has a lower *R* value. These figures demonstrate that it is more reasonable to recruit than to train workers when the demand has a relatively high volatility. The sharp increase in the latter part of the geometric case is due to the lost cost; the blocking probability grows very quickly.

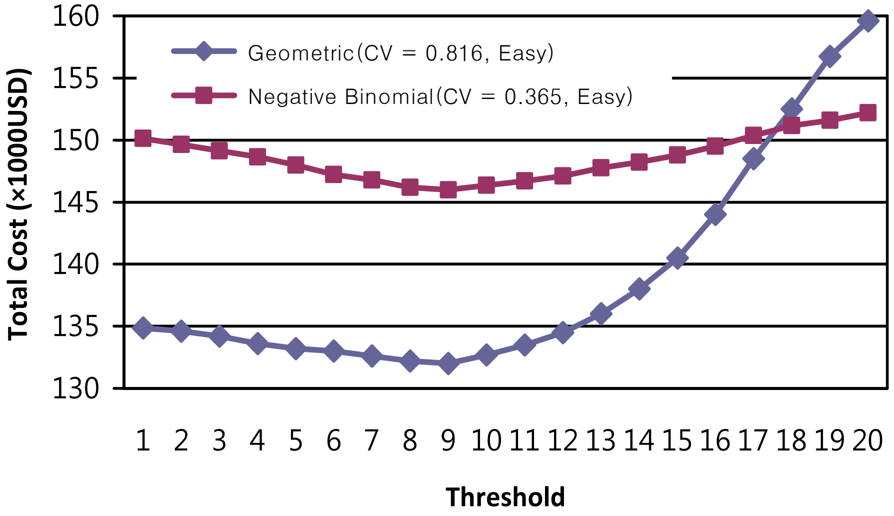

Figure 2a. Two Distributions with the 'Easy' Set

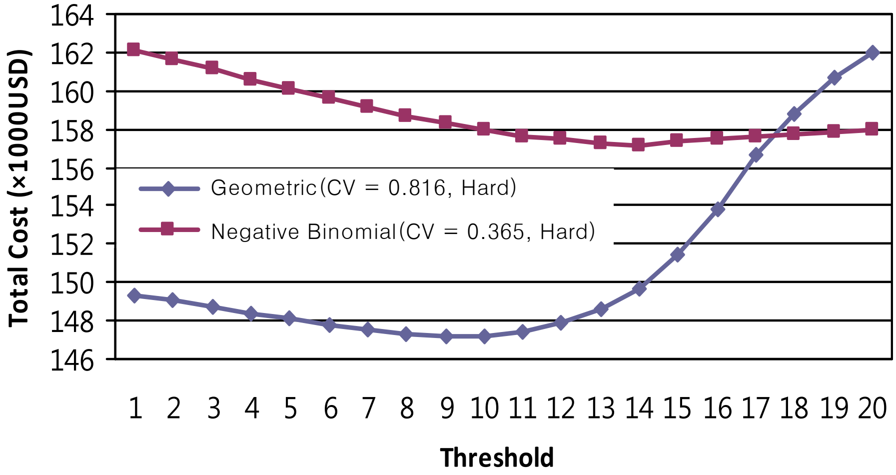

Figure 2b. Two Distributions with the 'Hard' Set

4.3.2 Effect of Recruiting Cost

Figure 3a and Figure 3b are intuitively clear. If it is hard to recruit experienced workers, the value of R is relatively high. Note that the difficulty of hiring experienced workers is expressed in terms of the cost. The second hypothesis is supported by these figures. For both distributions, the optimal value of R is higher when the cost structure is 'Hard.'

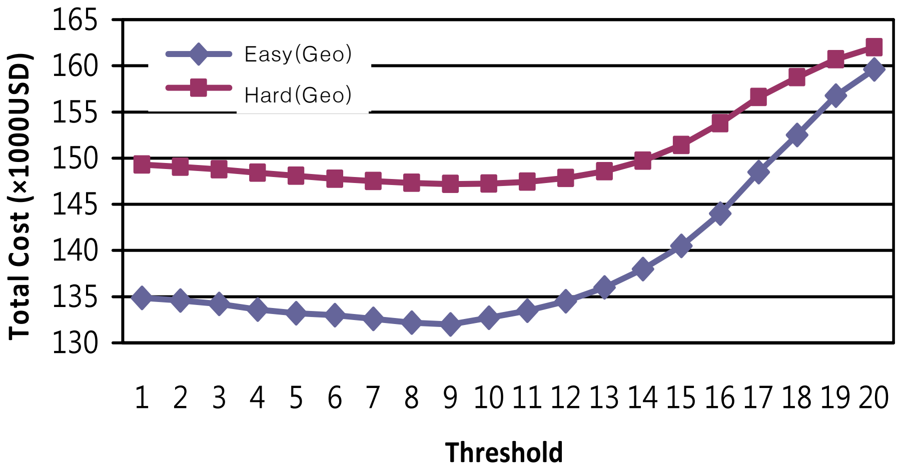

Figure 3a. Geometric Distribution with Two Recruiting Costs

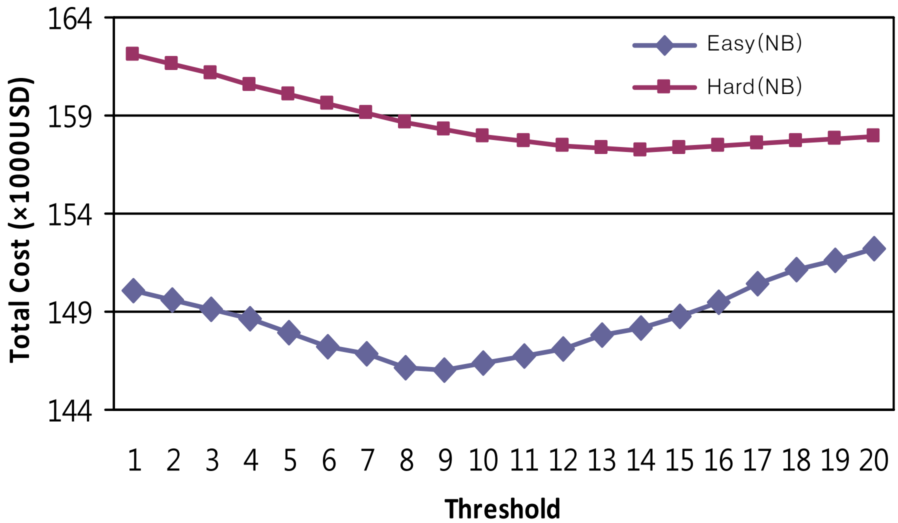

Figure 3b. Negative Binomial Distribution with Two Recruiting Costs

4.3.3 Effect of Holding Cost

We assume that if the holding cost increases keeping fewer workers would be more profitable. To investigate, we conducted two experiments where the holding cost is 6,000 or 8,000. The other conditions remain unchanged. The batch size distributions of Figure 4a and Figure 4b are the geometric and negative binomials, respectively. From Figure 4a and Figure 4b we can figure out when the holding cost gets larger the value of R gets larger, intending to fill up vacancies of buffer slowly. It could be possible that when the holding cost increases the value of R should be smaller. However, note that the state of our queueing model accounts for 'deficiency' in the buffer. Refer to the holding cost term, $C_H(K-L)$, in the objective function.

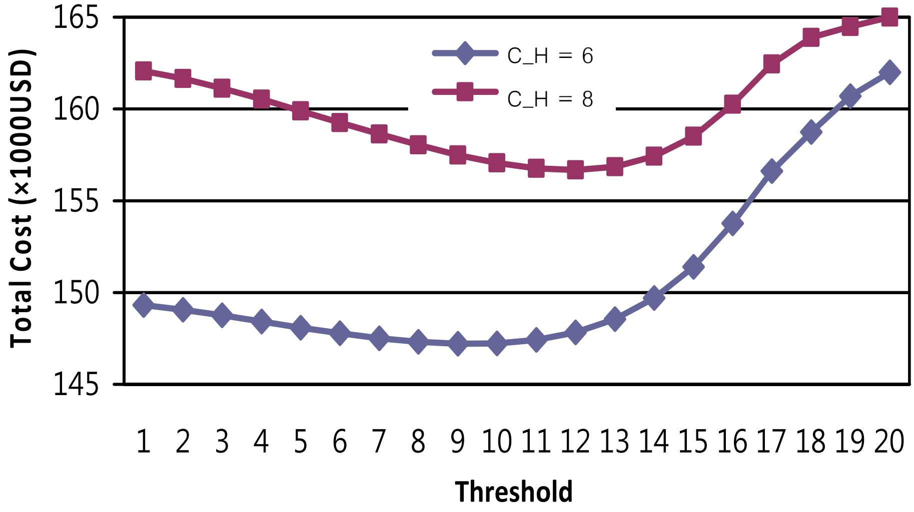

Figure 4a. Geometric Distribution Cases with Two Holding Costs

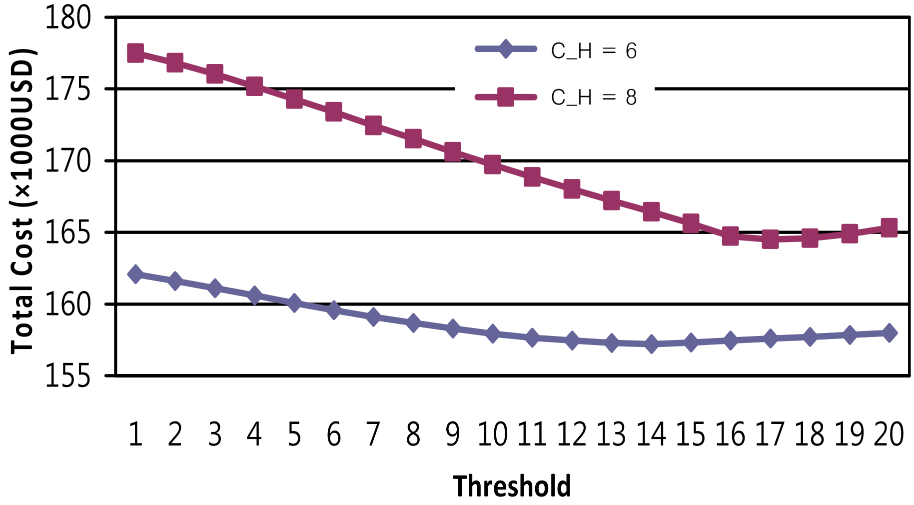

Figure 4b. Negative Binomial Distribution Cases with Two Holding Costs

4.3.4 Effect of Lost Cost

If the lost cost is relatively large, a company would prefer an urgent acquisition of experienced workers to prevent losing contracts. This means the value of R should be smaller when the lost cost is relatively large. Figure 5a and Figure 5b support this hypothesis. We increased the lost cost from 14,000 to 21,000 for two batch size distributions: geometric and negative binomials.

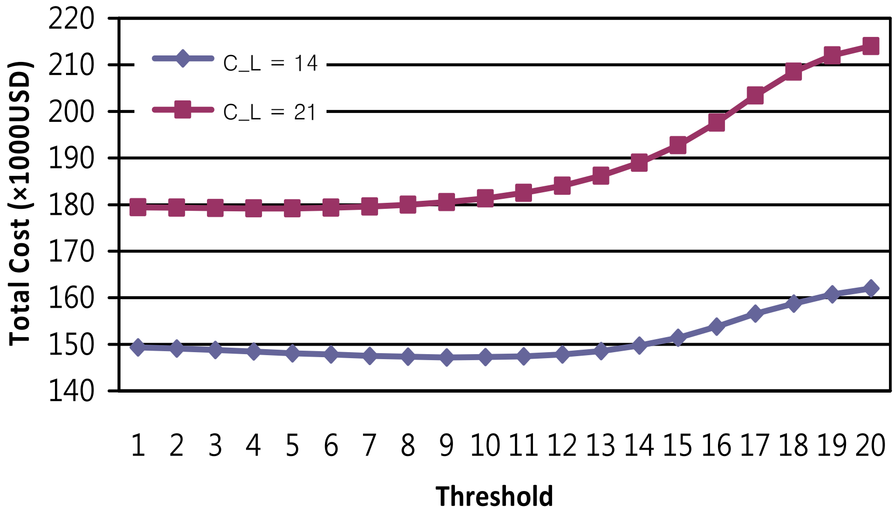

Figure 5a. Geometric Distribution Cases with Two Lost Costs

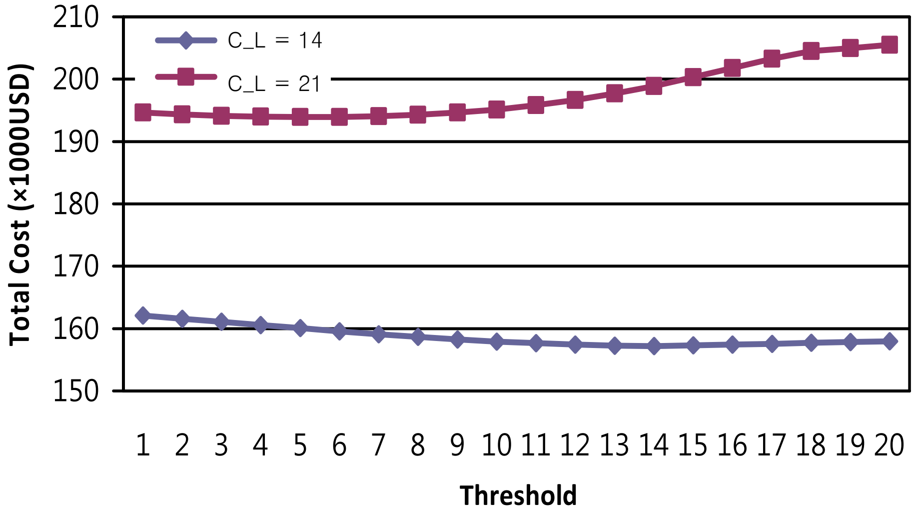

Figure 5b. Negative Binomial Distribution Cases with Two Lost Costs

4.4 Managerial Implications

Although many human resource managers in IT firms recognize that the volatility of workforce demand and the hiring cost are important factors when they decide whether to recruit experienced workers or apprentices, they are often unable to articulate specific values for reference. As the example illustrates, the volatility of workforce demand and the cost structure are significant components in workforce acquisition strategies. Our approach can help managers estimate the properties of workforce demands and the cost factors in human resource management. Managers can also use this approach to compare and evaluate different acquisition strategies for the various types of knowledge workers.

Parameter estimation is not always easy. The estimation of workforce demand properties from the survey has limited validity. A rational approach based on consistently accumulated data is recommended. The identification of service rates and cost factors requires additional effort. Even though the estimation in this paper is approximate, it is the first study to provide a quantitative guideline for human resource acquisition strategies.

5. Discussion and Future Research

As the world shifts from an industrial-based to a more knowledge-based economy, the question of efficiently managing knowledge workers grows in importance. Managers are not only required to avoid overspending on human resources but also to maximize business opportunities. This paper presents a stochastic model of staffing strategies for knowledge workers in an IT service firm. Although many disciplines have studied workforce planning for several decades, we believe this to be the first attempt at quantitatively addressing the problem of uncertain demand for a workforce. We applied our model to an information security service firm in South Korea. Numerical results were used to demonstrate the process of finding the optimal threshold value and clearly support our four hypotheses. Thus, we conclude that if future demands are volatile or the firm has to pay a higher price for each unit of demand lost, managers should recruit experienced workers rather than train apprentices, and if the firm has to pay a higher cost for hiring experienced workers or for holding a surplus worker, managers should train apprentices instead of recruiting experienced workers.

We propose four major directions for future research. First, we can develop our quantitative model to deal with more generalized situations of actual business. Generally distributed service time and batch mode service can be assumed. Also, we can extend our model to consider reassigning a worker who completes his project and returns to buffer. Second, we can specify the uncertainty of workforce demand. Factors such as a long-term business cycle and seasonality can clarify the uncertainty of workforce demand. Third, qualitative characteristics of the workforce, such as job types and levels, and knowledge types and levels can be considered. A skills framework is the first step for this research direction (see Jun *et al*. (2009) for the case of the information security industry). Fourth, to address the uncertainty of demand with leaner workforces, managers can consider cross-utilization of workers whose capabilities differ. Cross-trained workers have been widely adopted in both service organizations (e.g., float nurses in medical care (Campbell, 1999)) and manufacturing organizations (e.g., flexible workers in production lines (Sennott *et al*., 2006)). We can incorporate the capability level of cross-trained workers in the model.

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