A Sensitivity Analysis on the Impact of Uncertainties of the Supply and Demand of a Workforce on a Recruiting Strategy in an IT Service Company

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ABSTRACT

This paper investigates a managerial problem related to human resource planning for an IT service company which mainly carries out time-base projects. As the demand for new workers is subject to wide fluctuations, the firm should hire workers in advance and train them. However, the firm should urgently recruit skilled workers from outside the firm due to the shortages in the workforce. Hence, it is important for the firm to design an optimal human resource planning program so as to fulfill the needs of new IT service projects and minimize operation costs, though this involves a trade-off between holding excess workers to prepare for upcoming demand and recruiting experienced workers. This paper presents a quantitative model that describes the stochastic behavior of the supply and demands of the workforce. Numerical results pertaining to the optimal solution are given via a simulation.

Keywords  
Workforce management, Stochastic modeling, Supply and demand of a workforce, Recruiting strategy, Simulation

INTRODUCTION

This paper addresses human resource planning for an information technology (IT) service company. This business usually involves time-based projects which are accomplished by skilled workers or experts. If they are short of experienced workers before the kickoff of a new project, they are likely to lose a business opportunity. Considering the volatile demand for skilled workers, they 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 to hire and retain experienced workers. Eventually, 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 for the acquisition skilled workers.

The stochastic characteristics of the supply and demand of a workforce are considered here. Furthermore, a human resource strategy capable of meeting the demands of upcoming business projects and minimizing the operation costs related to the hiring and training of workers is analyzed. Cost factors such as hiring costs and training costs and the elasticity of the supply of experienced workers in the labor market have an impact on the retaining 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. Through a quantitative analysis, the process of deriving optimal strategies under various conditions is shown.

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 of Price et al. (1980) and in Purkiss (1981). In particular, Price et al. (1980) divided related research up to that point into two types of models. One type is a descriptive model that forecasts the result of various human resource policies of actual organizations. Markov models (Bartholomew, 1973; Grinold and Stanford, 1974), fractional flow models (Grinold and Marshall, 1977) and renewal models (Bartholomew and Forbes, 1979) were applied in previous studies. Another type, known as a normative model, can be defined as a model that obtains a set of feasible solutions considering the decisions related to workforce planning behaviors. Linear programming (Grinold and Marshall, 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 motives for a transition in an organization and classified the personnel system into more homogenous subgroups grouped by similar behavioral patterns. Anderson (2001) analyzed the knowledge for works which yields to differences in the quality of workforces. 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 ready 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 acquisition strategy of skilled workforce compared to those of previous studies. The results presented here also provide theoretical insight into human resource planning and offer a guide for making optimal decisions in practical situations.

**PROBLEM DESCRIPTION**

An optimal strategic mix of ‘planned’ and ‘Just-In-Time (JIT)’ acquisition of skilled workers is explored for an IT service in an IT service company considering the demand volatility of the IT service and the stochastic characteristics of the human resource supply. This issue is reminiscent of the well-known issue in the supply chain management (SCM) domain typically referred to as planned production vs. production on demand.

A managerial problem is considered in the following business situations regarding the demand and fulfillment of an IT service by a company:

- The demand for the IT service fluctuates over time, i.e., the demand is not deterministic, but stochastic.
- Thus, the company needs to retain an appropriate excess level of skilled workers to provide IT service to customers in a timely manner. However, as a holding cost for excessive workers is incurred, the excess level of workers must be controlled.
- At the beginning of each business period (such as the beginning of the month), the company makes a decision concerning the number of employees who will be hired during the period, considering the current level of available skilled workers in the company and the demand forecast for IT service during the period. It then executes the plan for the acquisition of new employees over the period.
- The newly hired workers must complete a course of training before they can be assigned to a new project the company will carry out for a customer.
- An employed worker leaves the company after a certain period of employment, but there are no dismissals by the company.
- The company tries to receive new contracts, without considering its current available workers, to maximize its market share (which is its prime business goal).
- If the company is short of skilled workers for newly contracted projects, the necessary skilled workers can be recruited from outside the company and can be allocated for the new projects immediately. However, in this case, overall costs tend to increase due to the additional recruiting cost and the managerial cost of unplanned activities.

This study seeks optimal solutions to the described managerial problem by controlling the mix of ‘planned’ and ‘Just-In-Time (JIT)’ acquisition of skilled workers according to the demand characteristics and workforce supply structure of the company. The demand characteristic can affect the optimal solutions, for example, in the following manner: If the volatility of demand is high, the company should utilize the JIT acquisition of skilled workers to avoid the large holding cost of excess workers due to the planned acquiring of skilled workers in advance. However, if the demand is steady, the company will prefer to acquire necessary workers in a planned manner to avoid additional recruiting costs. Similarly, the workforce supply structure can affect the optimal solutions, for example, in the following manner: If the mobility of skilled workers is high (i.e., skilled workers leave a company very often), the company should increase its relative use of planned acquisition, as this method makes it easy to change the number of excess workers in a relatively short term. However, if mobility is low, the company will prefer to acquire necessary workers as needed to avoid having to adjust the number of excess workers over a relative long term solely through attrition.

As shown in the next section, this paper presents a quantitative model for the described managerial problem of determining an optimal mix of planned acquisition and JIT acquisition of skilled workers under uncertain supply and demand conditions of the workforce. A stochastic optimal model is utilized for the analysis of the problem to capture the stochastic
characteristics of the supply and demand for skilled workers. Through this model, optimal strategies under various demand characteristics and cost structures are derived. These results provide theoretical insight into the problem and are expected to be helpful for organizations as they make optimal decisions in real practical situations.

MODEL
A stochastic optimization model is established in this section to formulate the managerial problem described in the previous section.

Workforce Demand
Time is assumed to be slotted for some managerial purpose. The company makes a decision based on slotted periods of time. Let $\Lambda(t) \geq 0, t = 0, 1, 2, \ldots$ denote the number of new projects occurring during time period $t$, and the $\Lambda(t)$ values are assumed to be independent and identically distributed (i.i.d.) and to be generally distributed nonnegative random variables. Projects that occur during period $t$ are started at the beginning of period $(t+1)$ regardless of the currently available workforce. Let $F(n)$ be the number of skilled workers required for the $n$th project to be accomplished. $F(n)$ values are assumed to be i.i.d. and generally distributed nonnegative random variables. It is also assumed that all required skilled workers are assigned to the project together from the beginning of the project but that each of the involved workers is released from the project, independently of the release of other involved workers, when they complete their own jobs. Let $S$ denote the length of time during which a worker is involved with a project; $S$ is assumed to be an i.i.d. discrete-time random variable according to a geometric distribution with parameter $\mu$.

Let $M(t)$ denote the overall demand for a skilled workforce at the beginning of period $t$, i.e., the number of skilled workers required for all projects currently undertaken by the company at the beginning of period $t$. If $A(t)$ is assumed as the number of skilled workers who are additionally required for new projects that arise during period $t$, it is easy to determine from the assumptions that $A(t) = \sum_{n=0}^{\Lambda(t)} F(n)$ and that the $A(t)$ values are also i.i.d. generally distributed nonnegative random variables. Additionally, if $B(t)$ is assumed as the number of workers who are released from the projects during period $t$, it is easy to determine from the assumptions that $B(t) \sim Bin(M(t), \mu)$, i.e., $B(t)$ follows a binomial distribution with parameters $M(t)$ and $\mu$, and

$$M(t+1) = M(t) + A(t) - B(t).$$

Thus, the overall workforce demand process $\{ M(t), t = 1, 2, \ldots \}$ is a discrete-time Markov chain (DTMC) because $A(t)$ and $B(t)$ are independent of the states before period $t$, provided $M(t)$ is given.

Workforce Supply
Let $R(t)$ denote the number of skilled workers who work for the company at the beginning of period $t$. Two means of supplying required skilled workers are assumed: planned acquisition and JIT acquisition.

Planned acquisition
At the beginning of each business period (such as the beginning of the month), the company makes a decision regarding the number of employees to be hired during the period considering the current level of available skilled workers in the company and the demand forecast for IT services during the period. It then executes the plan for the acquisition of new employees over the period. Each of the newly employed workers must be trained as an apprentice for a certain length of time, and the length of training time of each apprentice follows an i.i.d. geometric distribution with parameter $\alpha$. Let $U(t)$ denote the number of apprentices at the beginning of period $t$. To simplify the model, $U(t) = U$ is assumed; i.e., the company maintains a certain fixed size of the pool of apprentices regardless of time and/or other current states. $U$ then becomes a decision variable in this model. If $U$ increases, the portion of the planned acquisition to the total workforce supply will increase, and
the average number of excess workers will tend to increase. However, if \( U \) decreases, the portion of the JIT acquisition will increase and the average number of excess workers will tend to decrease. If \( X(t) \) is assumed as the number of apprentices who complete their training during period \( t \), it is easy to determine from the above assumptions that \( X(t) \sim \text{Bin}(U, \alpha) \).

**JIT acquisition**

If \( M(t) > R(t) \), i.e., the company is short of skilled workers for projects undertaken by the company at period \( t \), insufficient skilled workers will be recruited from outside the company at the beginning of period \( t \) and will be allocated for the projects immediately. Thus, if \( W(t) \) denotes the number of workers hired via JIT acquisition at period \( t \), then \( W(t) = \max \left(0, M(t) - R(t)\right) \).

So far, the inflow of skilled workers to the company has been described. The outflow of skilled workers from the company is now described. It is assumed that each skilled worker can leave the company at the end of each period with probability \( \beta \) and that the probability of leaving does not depend on the length of time during which the worker has been working for the company and/or other conditions. Thus, if \( Z(t) \) is assumed as the number of skilled workers leaving at period \( t \), it follows from the above assumptions that \( Z(t) \sim \text{Bin}(R(t) + W(t), \beta) \). At the end of period \( t \), there are the skilled workers employed via JIT acquisition during period \( t \) as well as skilled workers who were present at the beginning of period \( t \).

Considering the inflow and outflow of skilled workers at period \( t \) together, the following relationship holds:

\[
R(t+1) = R(t) + W(t) + X(t) - Z(t) = \max[R(t), M(t)] + X(t) - Z(t)
\]

Thus, the overall workforce supply and demand process \(\{(R(t), M(t)), t = 1, 2, \ldots\}\) is a two-dimensional discrete-time Markov chain (DTMC) because \( X(t) \) and \( Z(t) \) are independent of the states before period \((t-1)\) provided \( R(t) \) is given.

**Cost Structure**

The assumed cost factors are outlined in Table 1.

<table>
<thead>
<tr>
<th>Cost factor</th>
<th>Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holding cost</td>
<td>A fixed cost ( c_H ) is incurred for any surplus worker during a unit period.</td>
</tr>
<tr>
<td>Training cost</td>
<td>A fixed cost ( c_T ) is incurred for each apprentice during a unit period.</td>
</tr>
<tr>
<td>JIT recruiting cost</td>
<td>A fixed additional cost ( c_{JIT} ) is incurred each time an experienced worker is recruited via JIT acquisition.</td>
</tr>
</tbody>
</table>

Table 1. Cost factors

**Objective Function**

During period \( t \), the holding cost is incurred for \( \max\left[0, R(t) - M(t)\right] \) excess workers (if any), the training cost is incurred for \( U \) apprentices (regardless of \( t \), and the JIT recruiting cost is incurred for \( \max\left[0, M(t) - R(t)\right] \) insufficient workers (if any). As a result, to minimize the average long-term cost per unit period, the objective function of this model is defined as follows:

\[
\Delta = \min_{U \geq 0} c_H E\left[\max\left(0, R - M\right)\right] + c_T U + c_{JIT} E\left[\max\left(0, M - R\right)\right].
\]
where \( M = \lim_{t \to \infty} M(t), R = \lim_{t \to \infty} R(t) \).

As described by the objective function, the cost structure and the model parameters that affect \( M \) and \( R \) determine the optimal value of \( U \). The hypotheses are now given as it pertains to \( U \) in terms of the cost factors and the model parameters:

- Under the same parameters of workforce supply and demand, as the holding cost or the training cost increases, the optimal value of \( U \) decreases. That is, the company tends to prefer to acquire necessary workers in a timely manner, rather than in advance, to avoid a high holding cost of excess workers and/or high training costs.
- Under the same cost structure, as the mobility of skilled workers increases (i.e., the probability \( \beta \) of leaving the company increases), the optimal value of \( U \) increases. As excess skilled workers can be adjusted over the short term, the company tends to prefer to acquire necessary workers in advance. If the mobility of skilled workers decreases, the company will prefers to utilize JIT acquisition to avoid adjusting the number of excess workers over a relative long term solely through attrition.
- Under the same parameters of workforce supply and demand, as the elasticity of the supply of skilled workers increases (i.e., JIT recruiting becomes easier and the JIT recruiting cost decreases), the optimal value of \( U \) decreases. That is, the company tends to prefer to acquire necessary workers in a timely manner rather than in advance.
- Under the same cost structure, as the volatility of demand increases (i.e., the variance of \( A(t) \) increases), the optimal value of \( U \) decreases. As demand fluctuates greatly, planned acquisition may frequently lead to a large number of excess skilled workers. Thus, the company tends to prefer to acquire necessary workers in a timely manner.

These hypotheses are supported by a simulation of the proposed model in the next section.

### SIMULATION RESULTS

In this section, discrete-event simulation results of the stochastic optimization model are presented. It is assumed that the interarrival periods of consecutive contracts are distributed geometrically with a mean of 4, i.e.,

\[
P[A(t) = 1] = 0.25 = 1 - P[A(t) = 0].
\]

\( \alpha \) and \( \beta \) are set to 0.2 and 0.01, respectively. The group size of the \( n \)th project, \( F(n) \), is assumed deterministically as 3, essentially. The three cost terms, \( c_H \), \( c_T \), and \( c_{JIT} \) are 0.5, 1, and 4, respectively.

The parameters and distributions of the model are variable to verify the four hypotheses formed in the previous section. Henceforth, ‘the cost’ indicates the cost per unit period, and the total cost is defined as the sum of the three cost factors mentioned above.

#### Effect of Increase of Holding and Training Cost

To verify the first hypothesis, \( c_H \) and \( c_T \) are increased from 0.5 and 1 to 1 and 2, simultaneously. This hypothesis is verified by Figure 1. The x-axis represents a combination of holding and training costs. The y-axis denotes the optimal \( U \) value, where the cost is minimized for each combination of two costs. For example, a total cost is optimized (minimized) if \( U \) value is set to 6 under holding and training cost is 0.75 and 1.5, respectively, and other parameters have the same values as described in the previous section. This figure is the result of a discrete event simulation; the result has a stochastic drift.

#### Effect of Mobility of Skilled Workers

To check the effect of mobility, \( \beta \) was increased from 0.01 to 0.1, where \( \beta \) denotes the probability in which each employed skilled worker leaves the company at the end of each period. A larger value of \( \beta \) value implies greater mobility. Figure 2 supports the second hypothesis in the previous section.
Effect of the Elasticity of the Supply of Skilled Workers

To verify the elasticity of the supply of skilled workers, $c_{JT}$ was decreased from 4 to 2. This result is presented in Figure 3. This supports the third hypothesis that states that increased elasticity results in a decrease of the number of apprentices at the beginning of each period, as experienced workers are hired more readily if $c_{JT}$ is small.

Effect of the Volatility of Demand

To measure the effect of volatility, the distribution of the group size, $F(n)$, the number of skilled workers required for the $n$th project to be accomplished, is changed. Thus far, the value of $F(n)$ is deterministically 3. Henceforth, the value of $F(n)$ is 1, 3, 5, or 7 each with a probability of 0.25. In this case, the coefficient of variation is comparatively increased. In the former case, $F(n)$ has a deterministic value termed ‘Det’. In the latter case, $F(n)$ has greater volatility and is termed ‘Vol’. Figure 4 shows the difference of the two minimum $U$ values of the two cases: Vol – Det. An experiment was done 50 times, and the results are presented in Figure 4. Figure 4 verifies the hypothesis that states that increased volatility results in a

![Figure 1. Effect of an Increase of Holding and Training Cost](image1)

![Figure 2. Effect of Increased Mobility](image2)

![Figure 3. Effect of Increased Elasticity](image3)

![Figure 4. Effect of the Increased Volatility of Demand](image4)
decrease of the $U$ value, as the $U$ values of the Vol case are almost always smaller. In addition, the $U$ values of the Vol case were confirmed to be small in a t-test (significance level =0.05).

**CONCLUSION**

The stochastic behavior of the supply and demand of a workforce may have a significant effect on human resource management strategies. In this paper, a stochastic model of the supply and demand of a workforce in an IT service company was created. A cost function was formulated to determine the optimal recruiting strategy, and the impact of uncertainties in the supply and demand of the workforce on the recruiting strategy was analyzed. Numerical results supported the hypotheses regarding the planned acquisition and JIT acquisition of employees.

Recessions make the demand for the workforce decrease sharply and organizations are forced to lay excess manpower off. The model in this paper does not consider structural changes, such as layoffs, in the supply and demand process of the workforce. Models that are more realistic, such as those involving the seasonal and long-term trend characteristics of demand, catastrophic structural changes, dynamic decision-making activities on recruiting strategies, skill types and skill levels can be formulated in future investigations that build on the present results.

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