ISSN: 1940-9893 Vol.3, No.3, September 2010

Scientific Research

Journal of Service Science and Management

Chief Editor: Samuel Mendlinger

ISSN: 1940-9893

www.scirp.org/journal/jssm

Journal Editorial Board

ISSN: 1940-9893 (Print), 1940-9907(Online)
http://www.scirp.org/journal/jssm

J. Service Science & Management, **2010, 3, 287-382**
Published Online September 2010 in SciRes (http://www.SciRP.org/journal/jssm/)

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Volume 3 Number 3 September 2010

Journal of Service Science and Management (JSSM)

Journal Information

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J. Service Science & Management, **2010, 3, 287-297**
doi:10.4236/jssm.2010.33036 Published Online September 2010 (http://www.SciRP.org/journal/jssm)

Optimal Location of Facilities on a Network in Which Each Facility is Operating as an M/G/1 Queue

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Received June 21st, 2010; revised July 25th, 2010; accepted August 27th, 2010.

ABSTRACT

In this paper, we consider a facility location problem in which customers and facilities are located on a network, and each facility is assumed to be operating as an M/G/1 queuing system. In many situations, the customer chooses the nearest facility to receive service. Customer satisfaction is evaluated by the probability of waiting less than or equal to a certain time for a customer that is chosen randomly from all customers who arrives to the system. By using a computational method for obtaining the probability on the waiting time, we propose the computational heuristic methods for finding the optimal location. Numerical results show the following. First, it is shown that the tabu search with an initial solution generated by random numbers gives the near-optimal solution with the highest probability among several algorithms. Second, the computation time and solution quality are not sensitive to the sharp of the service time distribution. Third, the computation time and solution quality are highly sensitive to the system utilization. Fourth, the complete enumeration might be the best solution methodology for highly utilized systems.

Keywords: *Facility Location, M/G/1 Queues, Waiting Time, Tabu Search*

1. Introduction

Facility location problems are those which decide location of facilities that meet some decision rules, given the set of demand and potential facility sites. Most of researches have developed problems for the deterministic customer demand and the fixed utilization rate of facilities. In a real situation, however, customer demand fluctuates in time, and as a result, congestion often arises at the facilities. From a customer's point of view, congestion at the facility is an undesirable situation. In addition customers usually use the nearest facility among facilities. Thus, in addition to congestion, deciding facility location by considering the distance from customer's sites to the facility leads to the improvement of customer satisfaction.

The model presented in this paper is related to research on facility location which considers stochastic demand and congestion of facility on a network. Boffey *et al.* [1] have reviewed various facility location models with immobile servers, where it is assumed that a finite set of customer demand and potential facility sites are given. One of stochastic facility location models on a network has been introduced in Wang *et al.* [2]. Each facility operates as a simple M/M/1 queuing system in this model. Customers are assumed to travel to the nearest facility. The objective is to determine facility location minimizing the expectation of customer's total traveling time and sojourn time. Castillo *et al.* [3] considers two capacity choice scenarios for the optimal location of facilities with fixed servers, stochastic demand, and congestion. Each facility operates as an M/M/s queuing system. Berman *et al.* [4] analyzes the problem of locating a set of service facilities on a network when considering demand lost due to insufficient coverage and demand lost due to congestion. The objective is to find the facility location minimizing the number of facilities, so that the amount of demand lost from each source does not exceed a certain level. In these models, because of the complexity of the resulting model, they focus on approximate and/or heuristic solution methods. Elhedhli [5] proposes a linearization based on a simple transformation and piecewise linear approximations and an exact solution method based on cutting planes.

One of stochastic facility models with continuously distributed demand has been introduced by Baron *et al.* [6]. This model has a general distribution of the demand and general arrival and service processes. Facilities are assumed to be located at an arbitrary on a plane or space. Customers are assumed to travel to the nearest open facility. Moreover, the service level constraint is imposed to ensure adequate service at the facilities. The objective is to determine the number, location, and capacity of the facilities minimizing the sum of cost on locating facilities and servers. However, in a real situation, arbitrary possible facility sites are limited and we need to select several facility sites from several potential facility sites.

In this paper, facilities and customers are located in a network assuming that it is possible only to locate them in a limited space. Each facility assumes operating as a simple M/G/1 queuing system. In many situations, the customer chooses which facility to receive service by considering travel time to a facility. In our model, customers are assumed to travel to the nearest facility. Customer satisfaction is measured by whether or not customer's waiting time before receiving service is less than the permitted period. Thus, the objective is to find an optimal facility location maximizing the probability of waiting less than or equal to a certain time for arriving customers.

Wang *et al.* [2] have found an optimal approach facility location a greedy-dropping heuristic approach and tabu search approach with an initial solution generated by a greedy-dropping heuristic approach. In this paper, in addition to these approaches, we adopt a tabu search approach with an initial solution generated by random numbers. Although the probability of the objective can be represented by using Laplace transform, it is difficult to explicitly derive the probability by using Laplace inversion since the Laplace transform is very complicated. When the permitted time is given, however, it is able to compute the probability that is more than the permitted time (Tijms [7]). We propose the computational heuristic methods for finding the near-optimal location by using the method described in [7].

To evaluate the proposed algorithms, we made numerical experiments. The results show that: 1) An optimal solution can be searched with the highest percentage by using a tabu search approach with an initial by random numbers, 2) that computation time and solution quality are not sensitive to the sharp of the service time distribution, 3) that computation time and solution quality are highly sensitive to the system utilization, and 4) that complete enumeration might be the best solution methodology for highly utilized systems.

The paper is organized as follows. Our model and assumption are formally introduced in Section 2. Heuristic algorithms for finding a near-optimal location are proposed in Section 3. Computational tests of these heuristics are given in Section 4. Section 5 contains concluding remarks as well as future research.

2. Model

2.1. Assumptions and the Objective

Let $N=(V,E)$ be an undirected network with a finite set of nodes V and a set of arcs E. Let $X(\subseteq V)$ be a set of customer nodes and $F(\subseteq V)$ be a set of potential facility nodes. The sets X and F may overlap. Let d_{ij} be the shortest distance along the network between a customer node $i(\in X)$ and a potential facility node $j(\in F)$. **Figure 1** shows an example of a network. We define $u=|X|$ and $v=|F|$.

Demands which are generated by customers residing at customer nodes are called service requests. Service requests at customer node $i \in X$ are assumed to occur according to a Poisson process with mean rate λ_i. In order to receive service, customers travel to the nearest facility from customer nodes to facility nodes along the network. If there are multiple facilities that are equal to travel time from customer nodes, customers receive service in the facility which has the lowest index among them.

We assume that each open facility hosts a single server. Services are provided on a first-in-first-out basis. Service times are supposed to be independent among customers and have according to a general distribution $G_j(t)$ with expectation $1/\mu_j$. Thus, facilities operate as an M/G/1 queue. The objective is to select p facility nodes in F to maximize the probability of waiting less than or equal to τ for a customer that is chosen randomly from all customers who arrive to the system, where p is a positive integer and τ is a positive real value.

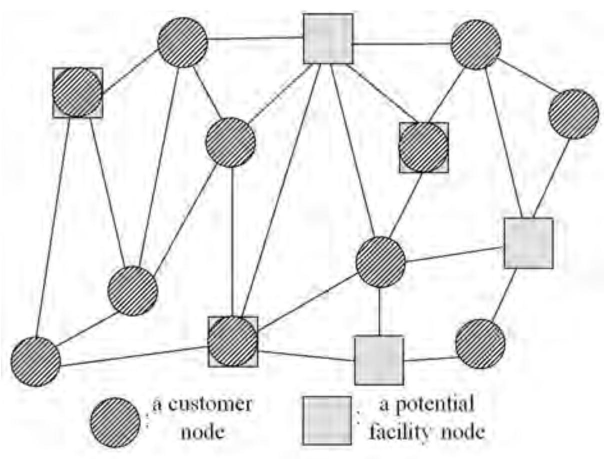

Figure 1. An example of a network.

2.2. Model Description

We define the following decision variables:

$$x_{ij} = \begin{cases} 1: \text{ if a customer at node } i \in X \\ \quad \text{ uses a facility at node } j \in F, \\ 0: \text{ otherwise.} \end{cases}$$

$$y_j = \begin{cases} 1: \text{ if a facility is located at } j \in F, \\ 0: \text{ otherwise.} \end{cases}$$

The objective of our model is to find an optimal facility location maximizing the probability that waiting time of customers is less than or equal to a certain time.

We define the following decision vectors $\mathbf{x}$ and $\mathbf{y}$:

$$\mathbf{x} = \begin{pmatrix} x_{11} & x_{12} & \cdots & x_{1v} \\ x_{21} & x_{22} & \cdots & x_{2v} \\ \vdots & \vdots & \ddots & \vdots \\ x_{u1} & x_{u2} & \cdots & x_{uv} \end{pmatrix},$$

and $\mathbf{y} = (y_1, y_2, \ldots, y_v)^T$.

Given $\mathbf{x}$ and $\mathbf{y}$, the probability in steady state that customer's waiting time W^j at a facility j is less than or equal to t can be represented by $P\{W^j \le t \mid \mathbf{x}, \mathbf{y}\}$. That is, the objective is given by

$$\sum_{i \in X} \lambda_i \sum_{j \in F(\mathbf{y})} x_{ij} P\{W^j \le \tau \mid \mathbf{x}, \mathbf{y}\},$$

where $F(\mathbf{y}) = \{j \in F; y_j = 1\}$.

Now we have the following mathematical programming formulation:

$$\text{maximize} \sum_{i \in X} \lambda_i \sum_{j \in F(\mathbf{y})} x_{ij}\ P\{W^j \le \tau \mid \mathbf{x}, \mathbf{y}\}, \qquad (1)$$

$$\text{subject to} \quad \sum_{j \in F} x_{ij} = 1, \quad \forall i \in X, \qquad (2)$$

$$\sum_{j \in F} y_j = p, \qquad (3)$$

$$\sum_{i \in X} \lambda_i x_{ij} < \mu_j y_j, \quad \forall j \in F, \qquad (4)$$

$$\sum_{k \in F} d_{ik} x_{ik} \le d_{ij} y_j + M(1 - y_j),$$
$$\forall i \in X, \forall j \in F, \qquad (5)$$

$$x_{ij} \in \{0,1\}, \forall i \in X, \forall j \in F,$$

$$y_j \in \{0,1\}, \forall j \in F.$$

We now formulate constraints in our model. Constraints (2) ensure customers certainly use a particular facility. A constraint (3) ensures facilities are located at p potential facility nodes in F. Constraints (4) show that all customers have to receive service. Constraints in set (5) indicate that each customer receives service at the facility which has the shortest travel time from him.

Let us discuss how to compute the probability of the objective function (1). Given y_j, x_{ij} is determined by the nearest assignment constraint described above. Consequently, the rate of service requests $\lambda_j(\mathbf{x})$ served at facility j can be represented by $\lambda_j(\mathbf{x}) = \sum_{i \in X} \lambda_i x_{ij}$. We denote the rate of utilization at the facility j by $\rho_j(\mathbf{x}) = \lambda_j(\mathbf{x}) / \mu_j$. The capacity constraint becomes $\rho_j(\mathbf{x}) < 1$ when $y_j = 1$. We denote the complementary distribution of waiting time distribution function $W^j(t) =$ $W^j(t) = P(W^j \le t)$ in steady state of an M/G/1 system in queuing theory by $\overline{W^j}(t) = 1 - W^j(t) = P(W^j > t)$. Laplace transform $\overline{W^j}^*(s)$ of $\overline{W^j}(t)$ is given by:

$$\begin{aligned} \overline{W^j}^*(s) &= \int_0^\infty e^{-st} P(W^j > t)dt \\ &= \frac{\rho_j(\mathbf{x})s - \lambda_j(\mathbf{x}) + \lambda_j(\mathbf{x})G_j^*(s)}{s(s - \lambda_j(\mathbf{x}) + \lambda_j(\mathbf{x})G_j^*(s))}. \end{aligned} \qquad (6)$$

where $G_j^*(s)$ is Laplace Stieltjes transform of service time distribution $G_j(t)$.

Since $\overline{W^j}^*(s)$ is very complicated, it is difficult to explicitly derive $W^j(t)$ by using Laplace inversion. When a value $t = \tau$ is given, however, it is able to compute the probability that waiting time is more than τ (Tijms[7]). In the numerical experiment of this paper, the method described in [7] is applied for computation.

3. Heuristic Approach

In this section, we explain heuristic approaches to compute an optimal facility location. Wang *et al.* [2] have found an optimal facility location using a greedy-dropping heuristic approach and tabu search approach with an initial solution generated by a greedy-dropping heuristic approach. In this paper, in addition to these two approaches, we adopt a tabu search approach with an initial solution by random numbers.

3.1. Greedy-Dropping Heuristic Approach

We explain the greedy-dropping heuristic approach. As preparation before applying this approach, we compute the shortest distance from all customer nodes in X to all facility nodes in F using Warshall-Floyd algorithm. Then, they are arranged in ascending order for each customer, that is, the facility which has the shortest distance from the customer has the higher rank for him.

Under the assumption of our model, if the travel times from the customer to several facilities are equal, the higher rank is assumed to be assigned to a facility which has the smallest index.

After that, we compute a facility location using the greedy-dropping heuristic approach. Initially, all facilities are assumed to be located at all potential facility nodes in F. After determining the facility location, customers receive service at a facility which is determined by the assignment constraint (5), that is, customers receive service at the facility which has the highest rank for him among located facilities. Next, we remove facilities one by one until the number of facilities reaches p. If a facility is removed, the customer who selected this facility will choose the facility with the next rank for him, and as a result the numbers of customers who are served at the rest of facilities increase. Consequently, the probability that waiting time W^j is less than or equal to τ decreases, and the value of objective function also decreases. Therefore, if there are multiple facilities for each of which the rest of facilities meets the capacity constraint (4) when it is removed, then we delete the facility which has the smallest diminution of the objective function value. The capacity constraint (4) is met if the sum of demands which are assigned to the facility does not exceed the service rate of the facility. This algorithm is repeated until one of the following stopping conditions is satisfied:

1) The number of facilities is equal to p.

2) The number of facilities is greater than p, and the capacity constraint (4) will not be satisfied even if any facility may be removed.

In case 1, the algorithm stops at a solution which meets all constraints, whereas in case 2 the algorithm stops at the current solution. That is, the solution in case 2 also cannot meet the number of facilities constraint (3). The greedy-dropping heuristic algorithm can be described as follows.

3.2. The Greedy-Dropping Heuristic Algorithm

We assume that the number of customer nodes is $|X| = u$ and customer nodes are numbered from 1 to u, and the number of potential facility nodes is $|F| = v$ and potential facility nodes are numbered from 1 to v sequentially. As a solution of facility location, let $Q(\subseteq F)$ be the set of nodes where facilities are located, and let $\psi(Q)$ be the corresponding value of objective function. Let $\varphi_j = \psi(Q \setminus \{j\})$ be the objective function value when facility j is removed from Q. When facility j is removed, if the capacity constraint (4) cannot be met, then set $\varphi_j = \psi(Q \setminus \{j\}) = 0$.

Preparation: First, we compute all $d_{ij} (i \in X, j \in F)$ using Warshall-Floyd algorithm. Next, because a customer at each node travels to facility which has the shortest travel time due to the closest assignment constraint, we arrange d_{ij} to each customer i in ascending order, facilities are ranked for each node in this order. If the distances from a customer node to facilities j_1 and $j_2 (j_1 < j_2)$ are equal, the rank shows preference for facility j_1.

Step 1: Locate facilities at all potential facility nodes, *i.e.*, set $y_j = 1$ for all $j \in F$ and $Q = \{1, \ldots, v\}$.

Step 2: Compute $\varphi_j (\forall j \in Q)$, then find $j_0 = argmax\{\varphi_j\}$.

If $|Q| = p+1$ and $\varphi_{j_0} > 0$, this algorithm stops after outputting $Q \setminus \{j_0\}$ because the number of facilities in $Q \setminus \{j_0\}$ reaches p.

If $|Q| \geq p+1$ and $\varphi_j = 0$ for all $j \in Q$, this algorithm stops after outputting Q since the solution cannot meet the capacity constraint (4) when any facility is removed. In this case, Q cannot meet the number of facilities constraint (3).

Otherwise, set $Q \leftarrow Q \setminus \{j_0\}$ and go to step 2.

3.3. Tabu Search Approach

In the greedy-dropping heuristic approach, it stops either at a solution that achieves a goal by reaching $|Q| = p$ facilities or that does not achieve a goal by stopping a location with $|Q| > p$ facilities. Thus, in order either to have the opportunity to investigate a high-quality solution, or to verify whether or not there is a solution in which the number of facilities is $|Q| = p$, we apply the tabu search approach.

To apply tabu search, we need an initial solution. We use a solution obtained by the greedy-dropping heuristic approach. In addition to a solution generated by an algorithm, we use a solution generated by random numbers as an initial solution. Here, a solution generated by random numbers is a one obtained by selecting p facilities with equal probability using random numbers.

When using the greedy-dropping heuristic approach to derive an initial solution, we use the solution as an initial solution, even if the solution in which $|Q| > p$ is output.

After an initial solution is found, tabu search approach is implemented. We define the neighborhood $H(Q)$ of a solution Q as a set of all possible pairwise facility swaps each of which is the swapping of one facility in the solution with the other facility not in the solution. For example, when $Q = \{a, b\}$ and $\overline{Q} = F \setminus Q = \{c, d\}$, the neighborhood is $H(Q) = \{(a,c), (a,d), (b,c), (b,d)\}$. At each iteration, we select a facility swap that provides the best objective function value (1). This swapping is repeated until one of the following stopping conditions is met:

1) The objective function value (1) shows no improve-

ment at successive K times.

2) Even if we carry out every facility swaps in the neighborhood, the solution cannot meet the capacity constraint (4).

In case that we use a solution of $|Q|>p$ as an initial solution, we apply the greedy-dropping heuristic approach to know whether the number of facilities can become p every time the facility swap is carried out. In case that a solution Q meets the above stopping condition and the number of facilities cannot be decreased, we output Q.

In case that the current solution Q is a local optimum, it is highly likely that the solution returns to Q again by continuing swaps after moving from Q to the other solution Q'. To avoid this, we prepare for the set of pairs of facilities called a tabu list. That is, we forbid swapping of pairs of facilities involved in this list.

To present the algorithm, we introduce the following additional notation:

- Q^*: the best solution found so far;
- L: the length of the tabu list;
- K: the maximum number of successive non-improvement swaps permitted;
- $TL(i,j)$: the number of iterations which are remained until facility pair (i,j) is permitted to come up for candidates of exchange.

Note that if $TL(i,j)>0$, pair (i,j) is in the tabu list and cannot be used in the next $TL(i,j)$ iterations. Using the defined notations, we denote the neighborhood of Q, *i.e.*, the set of feasible facility swaps, by $H(Q)=\{(i,j): i\in Q, j\in F\setminus Q, TL(i,j)=0\}$. The tabu search algorithm is as follows.

3.4. The Tabu Search Algorithm

Step 1: Let Q be the solution generated by the greedy-dropping heuristic approach or the random number. Set $Q^*=Q, k=0, TL(i,j)=0 (\forall i,j\in F)$, and set $H(Q)=\{(i,j): i\in Q, j\in N\setminus Q, TL(i,j)=0\}$.

Step 2: If $H(Q)$ is empty, stop and output Q^*. Otherwise, swaps are tried on all pairs in $H(Q)$, then we search the facility swap (s,t) in $H(Q)$ that meets the capacity constraint(4) and provides the best value of the objective function. If any facility swap in $H(Q)$ does not meet the capacity constraint (4), this algorithm stops after outputting Q^*. In this case, if $|Q^*|>p$, Q^* cannot meet the number of facilities constraint (3).

Step 3: If $\psi(Q\cup\{t\}\setminus\{s\})>\psi(Q)$, then set $k\leftarrow 0, Q^*\leftarrow Q\cup\{t\}\setminus\{s\}$; otherwise, set $k\leftarrow k+1$. If $k=K$, then we have performed K successive swaps that do not improve the objective function value, stop and output Q^*; otherwise, set $Q\leftarrow Q\cup\{t\}\setminus\{s\}$, $TL(s,t)=TL(t,s)=L$, $TL(i,j)=\max\{TL(i,j)-1,0\}$ ($\forall(i,j)\neq(s,t)$ or (t,s)), and $H(Q)$ is updated.

If $|Q|=p$, go to Step 2, and if $|Q|>p$, go to Step 4.

Step 4: To check whether or not the number of facilities can decrease from $|Q|$ to p, we apply the greedy-dropping heuristic approach. When we apply the algorithm, as an initial location of step 1 of this algorithm, we use the current solution Q. After applying the algorithm, set the derived solution as Q, and then go to Step 2.

Unlike the greedy-dropping heuristic approach, the approach with an initial solution obtained by the random number will generate the different solution every time. The solution obtained after the tabu search will strongly depend on the initial solution. In the numerical experiments of the next section, when we apply a tabu search with these approaches, we repeat the tabu search with different initial solutions five times, and output the solution which has the best objective function among solutions obtained after every tabu search. We can expect that the solution obtained will be improved, since tabu search approach is applied using a variety of initial solutions.

4. Computational Results

In this section, we numerically test heuristic approaches described in the previous section by applying various data, and discuss the results.

4.1. Experimental Setup

In this paper, the following three experiments are conducted by altering parameters.

1) the numbers of nodes
2) utilization rates and distributions
3) the number of potential facility nodes

Before starting experiments, we automatically generate networks by using the following method. Let N be the number of total nodes in a network, and let A be the number of total arcs in a network. Initially, we locate N nodes by using a uniform random number on a plane region of $0\le x\le X, 0\le y\le Y$. Next, we select two nodes from located nodes in a random manner, and connect them by an arc. At this time, the distance between two nodes is Euclidean, and we select A arcs with avoiding duplicates. Finally, by Warshall-Floyd algorithm, we check whether or not all nodes are connected. If some two nodes are not connected, we reattempt from a generation of nodes; otherwise, we conduct a numerical experiment by using the generated network. **Figure 2** shows an example of a network generated automatically as $X=100$, $Y=100$, $N=200$, $A=400$ by Mathematica 7.0.

In addition, in this paper, all programs are programmed by using C language and compiled by using Fujitsu C

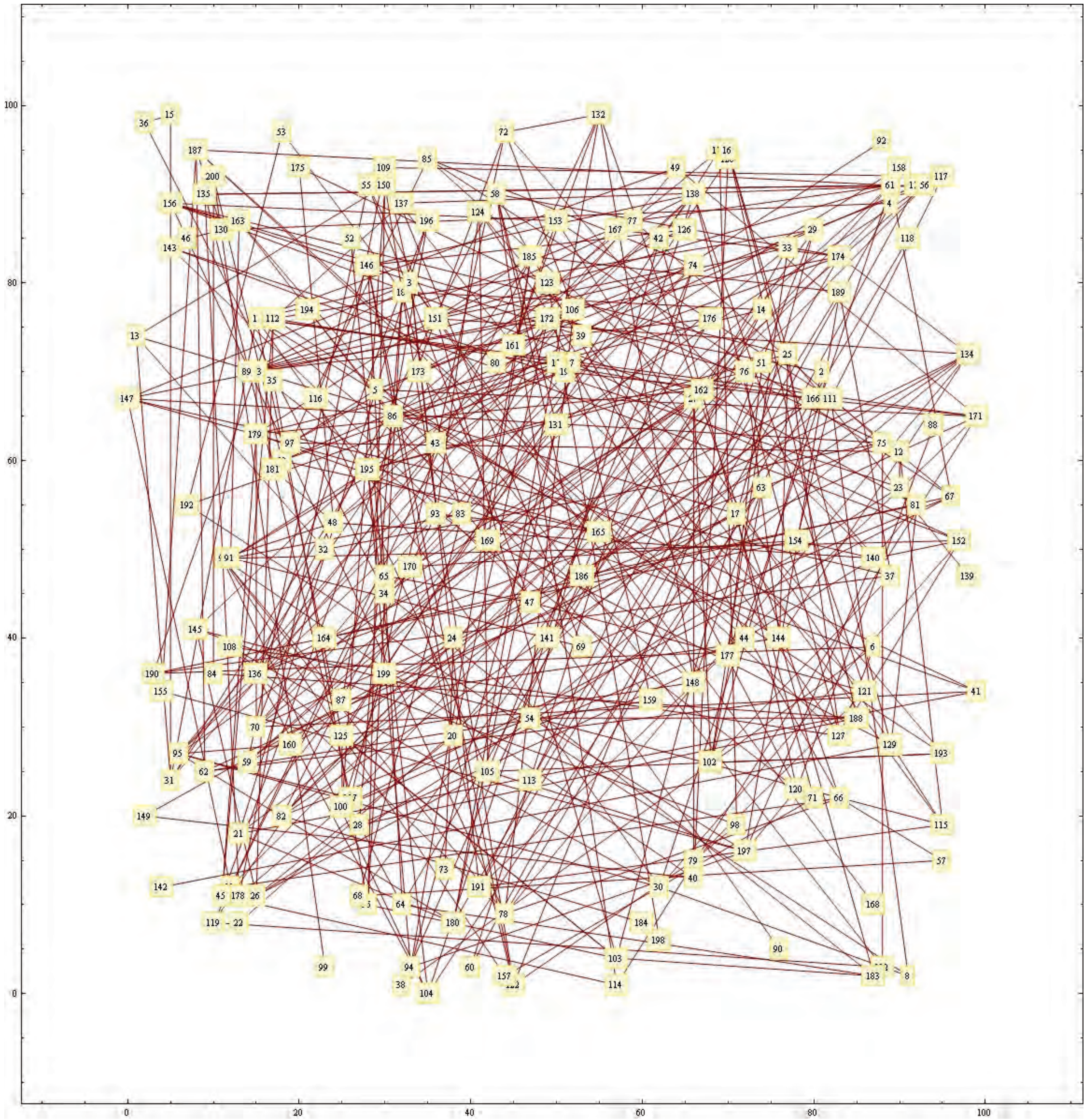

Figure 2. An example of a network using a numerical experiment.

Compiler, and executed on a PC with Intel(R) Core (TM)2 CPU4300 1.80GHz 3GB RAM.

First, we explain approaches and parameters used in numerical experiments. Approaches in numerical experiments are as follows:

- Exhaustive search [Combination] (COMB);
- Greedy-dropping heuristic approach (GD);
- Tabu search approach with an initial solution generated by using a greedy-dropping heuristic approach (GD-T);
- Tabu search approach with initial solutions generated by random numbers (RAND-T).

An exhaustive search is an approach that searches an optimal solution by computing objective values on possible all combinations. From now on, we call each approach by the corresponding abbreviated expressions.

As discussed in the last section, the RAND-T repeat tabu search with initial solutions generated by random numbers five times, and then they outputs a solution that provides the best objective function value among solutions obtained by tabu search.

We explain parameters used in experiments. Based on preliminary experimentation, the common parameters are set as follows:

- Numerical Laplace Inversion algorithm: the number of points conducted in the Laplace Inversion algorithm simultaneously is 32;
- Tabu search algorithm: the length of a tabu list is 7;
- Tabu search algorithm: the maximum number of successive non-improvement swaps permitted is 9.

In all experiments, we assume that each facility has the same service rates and each customer node has the same service request rates. In addition, we use the utilization rates to determine the service request rates. For example, if the number of facilities with service rate 1 is 3, the number of customer nodes is 10, and the utilization rate is 0.6, the service request rate of each customer node is set as $((1\times 3)\times 0.6)/10 = 0.18$.

In experiment 1, we analyze the effect of the numbers of nodes. **Table 1** shows parameters used in experiment 1.

In experiment 2, we analyze the influence in the case that utilization rates and distributions are altered. **Table 2** shows parameters used in experiment 2.

In experiment 3, we analyze the influence in the case that the number of potential facility nodes is altered. **Table 3** shows parameters used in experiment 3.

As combinations of parameters described above, experiment 1 has 5 combinations. Similarly, experiment 2 has 24 combinations and experiment 3 has 4 combinations. For each of 33 total combinations of parameter values, 10 problem instances are generated, leading to a total of 330 problem instances.

4.2. Experimental Results

Before showing the experimental results, we explain

Table 1. Parameters used in experiment 1.

Total nodes	100, 200, 300, 400, 500
Potential facility nodes	30
Customer nodes	Total nodes - 300
Empty nodes	0
Facilities	5
Distribution	Erlang (degree: 2)
Utilization rate	0.6
Service rate	1
Waiting time	1

Table 2. Parameters used in experiment 2.

Total nodes	500
Potential facility nodes	30
Customer nodes	470
Empty nodes	0
Facilities	5
Distribution	Exponential Erlang (degree: 2) Erlang (degree: 3) Erlang (degree: 5)
Utilization rate	0.6, 0.9
Service rate	1
Waiting time	1, 3, 10

Table 3. Parameters used in experiment 3.

Potential facility nodes	20, 25, 30, 35
Customer nodes	500
Total nodes	Customer nodes + Potential facility nodes
Empty nodes	0
Facilities	5
Distribution	Erlang (degree: 2)
Utilization rate	0.6
Service rate	1
Waiting time	1

following performance measures estimated by experiments.

1) Optimal rate (%): a fraction of instances in which the obtained solutions coincide with optimal solutions obtained by the COMB.

2) Relative error (%): an average of rates obtained by dividing absolute values of differences between the corresponding optimal objective values by the COMB and objective values by each algorithm by the former values.

3) Average computation time (seconds): average computation time until the solutions are searched by each algorithm after data of network is given.

In experiment 2, we also discuss fractions of experiments that reach p facilities for the solutions because the solutions obtained by heuristics do not reach targets on the number of facilities with high probability in some cases.

4.2.1. Experiment 1

We consider the result in the case that the number of nodes is altered. **Figures 3** and **4** show average computa-

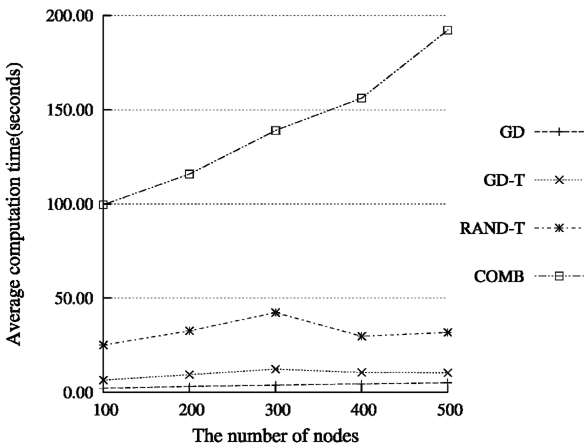

Figure 3. Average computation time in experiment 1.

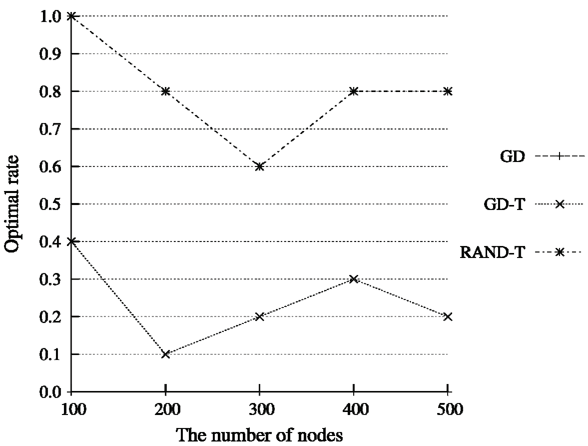

Figure 4. Optimal rates in experiment 1.

tion time and the optimal rate, respectively. **Table 4** shows average values of relative errors obtained by each algorithm. Relative errors are average values among experiments with 100 to 500 nodes. Note that they are almost constant on the number of nodes, and that all solutions in this experiment have $p(=5)$ facilities.

From **Figure 3**, we can see that average computation time of the COMB is increasing in the number of nodes. By contrast, average computation times of the other algorithms are not much increasing. Because the number of potential facility nodes is set to 30, the increase of the number of nodes implies the increase of the number of customer nodes. Consequently, if the number of nodes increases, the computation time necessary for determining a service facility for each customer also increases. In the case of the COMB, because the increase of the number of nodes has an influence on all combinations, the running time has increased greatly. On the other hand, because the other algorithms update solutions that meet conditions by removing and exchanging, they can search for the number of combinations that is much fewer than the number of combinations in the COMB. As a result, the increase of the number of nodes has little influence on the running time. Because the RAND-T searches solutions five times, that average time is longer than that of GD.

From **Figure 4**, we can see that the RAND-T typically finds the optimal solution. The fraction that it can search the optimal solution is about 80%. It is because the tabu search approach is conducted to a variety of directions thanks to a diversity of initial solutions. But, the GD cannot search optimal solutions at all. The GD-T also can search solutions only the average of about 30%. From **Table 4**, however, the relative errors of the GD is 4%, and GD-T has smaller errors. This means that most of cases in the GD and GD-T missed to escape from the local optimal solution and stopped to search before reaching the optimal solution in the tabu search.

4.2.2. Experiment 2

We show the experimental result in the case that service time distributions and utilization rates are altered. Although we conducted the experiment by using an exponential distribution and Erlang distributions (degree:2,3,5), there is not so much of differences between Erlang distributions. Thus we consider the cases of an exponential distribution and an Erlang distribution (degree: 3). **Table 5**

Table 4. Average of relative errors in experiment 1.

	GD	GD-T	RAND-T
Average of relative errors	0.039	0.016	0.001

Table 5. Optimal rate in the case that utilization rates and distributions are altered.

	Waiting time	GD	GD-T	RAND-T
Exponential: 0.6	1	0	0.2	0.6
	3	0	0.2	0.7
	10	0	0.3	0.9
Exponential: 0.9	1	0	0.2	0.2
	3	0	0.3	0.1
	10	0	0.2	0
Erlang(3): 0.6	1	0	0.2	0.8
	3	0	0.2	0.8
	10	0	0.3	0.5
Erlang(3): 0.9	1	0	0.2	0.1
	3	0	0.3	0
	10	0	0.2	0.1

shows the optimal rate in the case that utilization rates and distributions are altered, and **Table 6** shows the average computation time.

Table 7 shows rates on searching solutions with targets on the number of facilities generated by RAND-T. In RAND-T, we conduct tabu search with different initial solutions five times for each instance, and we output a solution that provides the best objective function value of them. Thus, because we conduct experiments by using the same parameters, **Table 7** shows average of 50 total experimental results. **Table 8** shows rates of experiments succeeding in finding solutions with targets of the number of facilities by the other algorithms when distributions and utilizations are altered.

From **Table 5**, for any utilization rates and distributions, optimal rates of GD and GD-T are almost the same as in Experiment 1. They are not influenced by τ. Consequently, we can see that the distribution (Exponential or Erlang) has almost no impact on optimal rates.

Table 6. Average computation time in the case that utilization rates and distributions are altered.

	Waiting time	GD	GD-T	RAND-T	COMB
Exponential: 0.6	1	4.586	9.407	30.505	176.562
	3	4.595	9.473	28.199	176.566
	10	4.565	10.506	28.420	176.538
Exponential: 0.9	1	4.530	5.964	0.144	12.264
	3	4.527	5.866	0.109	12.253
	10	4.497	5.597	0.108	12.324
Erlang(3): 0.6	1	5.412	10.981	33.192	206.807
	3	5.414	11.053	35.014	206.758
	10	5.381	12.249	36.438	206.691
Erlang(3): 0.9	1	5.350	6.686	0.117	12.633
	3	5.339	6.877	0.120	12.681
	10	5.315	6.567	0.153	12.342

Table 7. Rates of experiments reaching targets of the number of facilities in solutions generated RAND-T.

	Waiting time	the utilization rate 0.6	the utilization rate 0.9
Exponential	1	0.94	0.04
	3	0.88	0.04
	10	0.92	0.06
Erlang(3)	1	0.96	0.02
	3	0.92	0.02
	10	0.96	0.06

Table 8. Rates of experiments finding the solution that achieves targets of the number of facilities in the case that utilization rates and distributions are altered.

	Waiting time	GD	GD-T
Exponential: 0.6	1	1.0	1.0
	3	1.0	1.0
	10	1.0	1.0
Exponential: 0.9	1	0.4	0.7
	3	0.3	0.7
	10	0.3	0.7
Erlang(3): 0.6	1	1.0	1.0
	3	1.0	1.0
	10	1.0	1.0
Erlang(3): 0.9	1	0.4	0.7
	3	0.3	0.7
	10	0.3	0.7

From **Table 6**, average computation time also are not influenced by τ. This means that the distribution have little effect on the searching. As utilization rates are large, however, **Tables 5** and **6** show that we can hardly find solutions even if we search from a variety of directions in a random manner. In the case that the utilization rate is 0.6, we can almost find solutions that meet targets of the number of facilities, but in the case that the utilization rate is 0.9, we were hardly able to find solutions that meet targets of the number of facilities. This is because the number of the solutions that meet the capacity constraint (4) decreases in the utilization rapidly. As shown in **Table 8** the same phenomenon appears in the other algorithms. Thus, in the case that the utilization rate is too large, it is difficult for our algorithms to search optimal solutions or near-optimal solutions. In the case that the utilization rate is 0.9, however, we can see that the COMB can search optimal solutions quickly. The computation is done quickly because the COMB skips the computation with respect to the solution that does not meet the capacity constraint (4) as a large majority of the solutions cannot meet this constraint. Thus, in the case that the utilization rate is high, the COMB is the best algorithm in this instance.

4.2.3. Experiment 3

We consider the results in the case that the number of potential facility nodes is altered. Targets of the number of facilities are set to 5. **Figure 5** shows optimal rates in the case that the numbers of potential facility nodes are altered, and **Figure 6** and **Table 9** show average computation time and relative errors respectively.

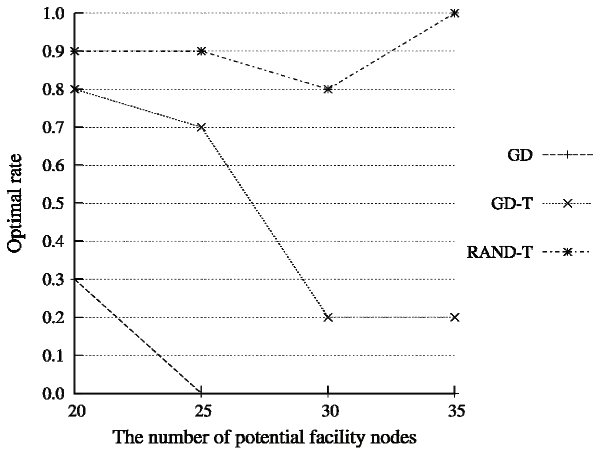

Figure 5. Optimal rates in the case that potential facility nodes are altered (A target of the number of facilities: 5).

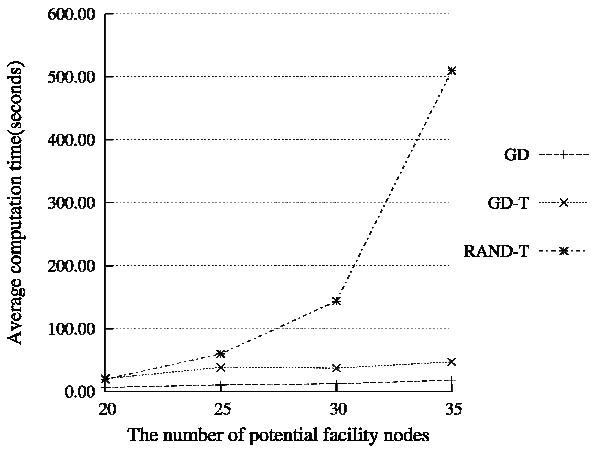

Figure 6. Average computation time in the case that potential facility nodes are altered (A target of the number of facilities: 5).

Table 9. Relative errors in the case that potential facility nodes are altered (A target of the number of facilities: 5).

	GD	GD-T	RAND-T
Potential facility nodes: 20	0.01	0.00	0.00
Potential facility nodes: 25	0.03	0.01	0.00
Potential facility nodes: 30	0.02	0.00	0.00
Potential facility nodes: 35	0.02	0.00	0.00

From **Figure 5**, we can see that the GD was hardly able to search the optimal solution. The GD-T tends to decrease optimal rates as the number of facilities increases. We can see that the optimal rates of the RAND-T are higher than those of the other algorithm. From **Table 9**, even if all algorithms increase the number of potential facility nodes, relative errors hardly alters and they are very small. The relative error of the RAND-T is smaller than the other algorithm although the optimal rate is greater. Thus, it can be concluded that the RAND-T is the best algorithm to search an optimal facility location in our model.

4.3. Analysis of Path Searched at the Tabu Algorithm

The GD-T moves nearer to the optimal solution in comparison to the solution generated by GD, but do not reach the optimal solutions in many cases. We discuss the reason why their approaches cannot search an optimal solution.

Figure 7 shows a part of the path search of the GD-T, which searches in the order of from the facility swap 1 to the facility swap 5. The origin of each arrow shows the facility that is removed by exchange, and the end of the arrow shows the facility that opens by exchange. From **Figure 7**, we can see that the location returns to the first location by the successive exchange from the facility swap 1 to the facility swap 3. That is because this algorithm searches toward the first solution by improving the solution by the facility swaps 2 and 3 after it is updated to the not-improved solution by conducting the facility swap 1. In addition, because the algorithm cannot exchange facilities by swap 1 in tabu list, the solution returns to the initial location by conducting the facility swap 5 after the solution is updated to the not-improved solution by conducting the facility swap 4. After that, because the swap used so far cannot be conducted, this algorithm exchanges facilities by the other swaps included in the neighborhood, and then this algorithm stops by reaching the maximum number of successive non-improvement swaps permitted. That is one of the reasons why the algorithm sometimes accepts to update toward the worse solution.

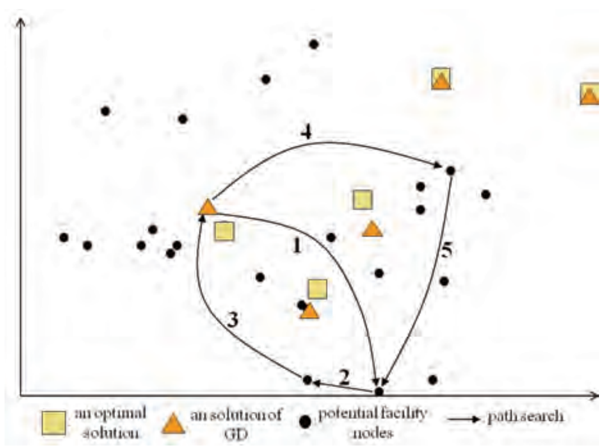

Figure 7. A part of the path search of the tabu search algorithm.

5. Conclusions and Future Work

This paper focuses on a facility location problem with stochastic customer demand and congestion where customers travel to facilities to receive services. We explain a model that located customers and facilities on network and provide services at each facility operating as an M/G/1 queuing system. The objective of our model is to search an optimal facility location maximizing the probability of waiting less than or equal to a certain time for a customer that is chosen randomly from all customers who arrive to the system. In order to search an optimal location, we propose three heuristic algorithms: GD, GD-T, and RAND-T. We conduct numerical experiments by using these algorithms and the COMB and discuss the properties of these algorithms.

Based on the results of numerical experiments, we can search an optimal solution with the highest percentage by using the RAND-T in many cases. However, in the case that utilization rates are high, we need to search an optimal solution by using the COMB because it is difficult for the other three algorithms to search an optimal solution. The tabu search approach has a property that it returns to the first location through several facilities, which results in stops at the local optimal solution. Although we assume that the number of servers at each facility is set as one, multiple servers will be considered as more realistic problems. These are also left in the future.

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J. Service Science & Management, **2010, 3, 298-308**
doi:10.4236/jssm.2010.33037 Published Online September 2010 (http://www.SciRP.org/journal/jssm)

A New Framework for Designing E-Government Procurement in China Based on Ontology and Business Component*

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Received April 26th, 2010; revised June 5th, 2010; accepted July 8th, 2010.

ABSTRACT

Electronic government (e-government) procurement is one of the most important activities in China. The paper consists of three parts. First, the paper introduces current situation of China's e-government procurement system which includes the overall technical level, application level, and the existing problems. Based on the problem brought forward from the first part, the paper considers that a better solution is to apply business component theory and business component framework in the construction of e-government procurement, as it can solve the problems that block the development of e-government procurement in a more convenient way. The paper constructs the Business Component (BC) framework for the e-government procurement, analyzes the superiority of BC framework and describes a methodology for the application of BCs in e-government procurement. The paper utilizes semantic model for workflow by using ontology modeling tool Protégé, uses ontology model database to store and manage workflow model, and builds a permission-based and user-involved workflow. At last, the paper takes public bidding, a main e-procurement method in China as an example and uses Appfuse and Osworkflow to prove the validity of the framework and methodology.

Keywords: *Business Component, E-Government Procurement, Appfuse, Osworkflow, Ontology, Protégé*

1. Introduction

E-government procurement is gaining more attention in the research field recently. Government administration is a kind of knowledge-intensive process from the view of service type [1,2]. Participants in the process must possess some professional knowledge of different industry fields, which makes the process more flexible and changeable. These features are more remarkable in the e-government procurement.

In China, government procurement refers to state organs, institutions and organizations at all levels that use fiscal funds to centrally purchase goods, works and services within a procurement directory or procurement standards noted above. The process of procurement is limited in a strict way. The most complex, important and representative method is public bidding (a main e-procurement method in China). It helps the government to obtain better working equipment or service in a relative low price, improve the working efficiency and reduce financial expense [3]. In China, The standard structure of government procurement can be seen in **Figure 1**.

In general, a municipal level of government procure-

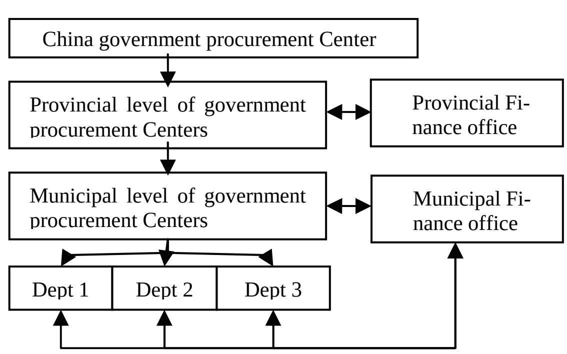

Figure 1. Structure of government procurement in China.

*This paper is a thorough extension of a paper of ICDS 2008 (Li, *et al.*, 2008).

ment Center usually contains three departments. As is seen in **Figure 1**, Dept1 represents the marketing office, whose main function is responsible for commodity procurement; Dept2 represents the procurement office, which is responsible for procurement of large-scale projects. Dept3 represents the integrated office, which is mainly responsible for coordinating the relationship among other departments.

Government procurement has gradually become more standardized and large-scale in recent years. The scale of government procurement is more than 590 billion, up 27%, and capital saving rate of 11.3% [4]. In 2006, China issued the standards of e-government procurement, including standards of architecture, security, and selection of software components, plug-in software, and the functional requirements which should be achieved.

Different with other government office automation (OA) system and e-government citizens-oriented service system, e-government procurement is a special system that is a process of transaction between governments and enterprises. The e-government procurement has its unique characteristics.

According to the analysis above, the system of government procurement requires high level of flexibility, agility and adaptability because it is knowledge-intensive and its process should be changed frequently. The paper considers that Business Component (BC) theory and its framework can fit the demands of e-government procurement commendably.

Definition: Business component (BC) represents a kind of software implementation of an "autonomous" business concept or business process. It is composed of all software components necessary to express, implement, and deploy a business component as an autonomous, reusable element of an information system [5].

BC theory's main idea is "to build on-demand". In this paper, to apply BC framework and ontology theory in e-government procurement, we should have an in-depth understanding on that area and a mature method to build concept model. We use FODA (Feature-Oriented Domain Analysis) [6] to make analysis on the function and process of e-government procurement and use entity-append [7] approach to design BCs.

The structure of the paper is as follows: in Subsection 2.1, we use FODA to analyze the function and logic process of government procurement, build domain BC to identify index system and utilize cluster algorithm [8-11] to abstract and design BCs that can be reused in e-government procurement. In this section, the paper summarizes the superiority of each business component framework and designs a unique framework for e-government procurement by consulting Component-Based Software Development (CBSD) [12] for BCs to deploy. In Subsection 2.2, the paper introduces the structure of a typical BC. In Subsection 2.3, the paper discusses how to use J2EE light weight architecture to develop the system under BC framework. In Subsection 2.4, a user participation workflow based on ontology is introduced to enhance the flexibility of the framework. In Section 3, an instance is introduced to describe how to use the framework to develop public bidding (a main procurement process approach) to validate feasibility and superiority of the system.

2. Business Component Framework Based on Light Weight J2EE Architecture

2.1. Business Component Framework

In this paper, based on traditional BC framework, we make some improvement and innovation on it. The research on BC framework is mature, but there is no related research on the application of BC framework in government procurement in China, so the main purpose of this paper is to analyze the domain characteristics of government procurement in China and build up a domain BC framework that can support government procurement in China more efficiently. The main innovation is listed below:

1) Use FODA to analyze the particular domain of government procurement in China.

2) Consider the advantages of several main BC framework [6,8,9,13,14] that can be used in the government procurement, reconstruct them to meet the requirement of government procurement and research on how to integrate them into J2EE light weight architecture.

3) Research on how to make use of those advantages to construct BC framework, abstract and design BCs that is based on government procurement in China.

4) Adopt several evaluation approaches to estimate the effect of the BC framework that is built for government procurement.

First, we make domain classification from a strategic level. We consider that the research object cannot be limited to existing procurement but we also need some forward-looking about the development of government procurement. The organization structure should be meaningful in strategic level, and thus we adopt a coordination mechanism among decision-making, implementation, and supervision [4]. We can use that mechanism to guide the construct of government procurement system.

According to the analysis above, the domain can be divided into four main categories: decision categories, implementation categories, supervision categories and finance categories. The main function of decision categories is to decide the evaluation index system of bidding for a project, use qualitative and quantitative methods to analyze each bidder and judge which bidder can be successful in the bidding. Implementation categories implement the decision made by decision-makers, mainly including examining, approving and generating basic index table, product or project information table, user requirement table and etc. Finance categories add finance information to the basic table in accordance with the information the table has offered.

Each category has a BC database which contains a collection of standard reusable BCs, and the BC database consults Jun Ginbayashi and Rieko Yamamoto's ComponentAA mechanism [13], builds a detailed data model, and maps the model to the object. By using that approach and entity-append mechanism, we divide BCs into entity components (ECs), process components (PCs), abstract domain business components (ADBCs), business-level core business components (BCBCs), abstract core business components (ACBCs), customer core business components (CCBCs).

ADBCs are the proper characteristics in e-government procurement, which encapsulates the process and functions that is regulated by law and cannot be modified. They build the system frame to integrate other BCs. PCs is the set of meta-process which can describe concrete section of business process, while ECs is the set of meta-function which can realize some function of the system. ACBCs and BCBCs is the organic combination of ECs and PCs. The difference is that ACBCs is a kind of general BC, that means the attributes and functions it provides are common and can be reused not only in e-government procurement domain but also in other domain such as OA or distribution system, and inherit [15,16] mechanism is used to realize that general BC, but BCBC considers the reusable in the same domain, it abstracts the common properties of several similar processes in the same domain and encapsulates those properties into a BCBC, it has several parameters, and it can switch to different process by re-configuring the parameters. By using IoC [16,17] mechanism, the parameters can directly point out which template model should be applied. So when changes happen, we just modify the parameters in service layer, then the rest work can be done automatically by using IoC mechanism. CCBMs emphasize the requirement of customers and design the business components that can satisfy the specific demands of customers.

Papers [9-11] introduce the clustering methods to identify and design business component from the set of meta-process and meta-function. According to the study of those articles, we summarize their principles and use their methods to cluster meta-function and meta-process:

What's more, each category contains four modules in the BC framework, which are mathematic base, knowledge base, organization management module and template module. Mathematic base provides many kinds of mathematic tools and decision algorithms to support data analysis and make decision. Knowledge base provides an expert system for users to realize knowledge management and sharing. Organization management module defines the roles and authority of the system, and use user authentication mechanism to realize the dynamic banding between user and role [17]. Template module considers that one BC may choose different actions when confronting different situations, so it builds many templates to deal with changes. The structure of the framework can be seen in **Figure 3**.

The framework is divided into four layers that are user interface (UI) layer, business process layer, service layer, data operation layer and data layer. UI layer contains User Interface Business Components (UIBCs) which can make various UI interfaces for users to communicate with computers and many kinds of tables. Business process layer describes the logic of real business process and builds model for it by using Osworkflow (a kind of open source workflow software which is developed by Java). It divides the whole process into several stages, each stage is further divided into several activities, and each activity is a concrete task that is assigned to certain person. It needs BCs from service layer to implement response work. The main management tools of service layer are Application Context Affairs. All BCs should register in service layer, provide their addresses, functions and interfaces to Application Context Affairs so that it can find and use them, which are included in BC management.

2.2. Structure of Business Component

According to Subsection 2.1, BCs are divided into several types including ADBCs, BCBCs, ACBCs, CCBCs, ECs and PCs. Each business components should contain at least one of the two parts: PCs and ECs. Take ADBCs as an example, whose process is composed of several groups of meta-processes and entity is also consisted of several groups of meta-functions [11-13]. There is an organic link between meta-process and meta-function. We consider the meta-process and related meta-function as an individual object, and the object can exhibit typical structure of Business Component. The construct of the objects can be seen in **Figure 2**.

The structure has two layers that are meta-process layer and meta-function layer. Meta-process layer uses business interface to obtain the external information and service requirement, then sends them to the business proxy, and business proxy uses IoC mechanism [16-19] to select specify business service to realize service requirement.

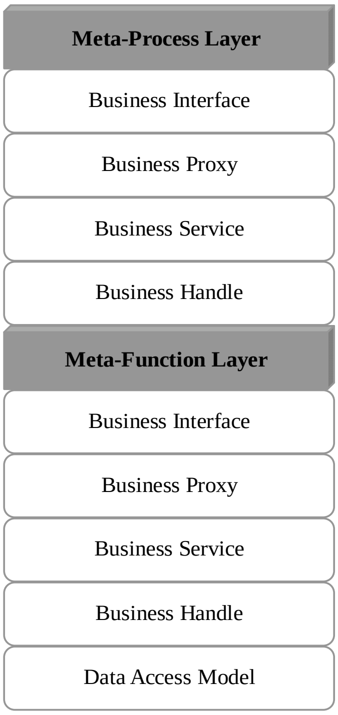

Figure 2. Structure of object.

The services in meta-process layer should be supported by the meta-function layer, which provides functions to realize the services that are brought by meta-process layer in the same way as the meta-process does, but the different is that meta-function layer need to handle the database. As shown in **Figure 3**, the ADBCs need to encapsulate the operation of database too.

In this paper, we adopt Hibernate to obtain data object, and deal with the database just like invoking a general programming but does not need to insert into specify SQL language.

2.3. Application of Appfuse and Osworkflow

The main tools applied in the component based framework are EJB, web service and COM. Considering the feature of e-government procurement that is introduced in Section 1, we decide to choose a more agile architecture which integrates much technical superiority, possess nicer architecture support that can make flexible configuration. Light weight J2EE architecture is a good option, and Appfuse is one of the most excellent products in light weight J2EE architecture. It integrates the main software design frameworks of java such as Struts, Spring and Hibernate so we can use their respective specialties to construct three layers architecture that is inherited and abstracted from business component based methodology. It uses templates and configuration files to support fast development. Strong configuration function is a main characteristic in business component based framework that is described in literature [18].

In this paper, considering frameworks' respective advantages, we use Osworkflow to design the process of e-government procurement and utilize Appfuse to build the business component based architecture and design the management mechanism of business components [20,21]. We use Osworkflow to design the meta-process models and assemble them to form an integrate e-government procurement process, use JSP and Servlet to design UI and transfer information to Osworkflow, use Spring to implement and manage business components, and use Hibernate to implement database CRUD operation.

2.4. User Participation Workflow Model Based on Ontology

The e-government procurement is an interaction process among different enterprises, government departments and organizations, which involves different auditing processes, The processes are different and changed frequently, thus, the functions of the roles are also changed, so does the structures of the organizations. It is hard to define all the process and obtain the meta-process by usual method. Therefore, it is difficult to satisfy user's requirement. For example, in the past, government used inquiry approach for purchasing products and projects, the total value of which are less than 50 million Yuan. Now, in order to improve work efficiency, the government adopts fixed procurement method for different products. It is very difficult for us to update existing system to satisfy the changes. Redevelopment is considered as a waste of money and time and we also cannot be certain that the new system could be competent in the future.

So one method to solve that problem is to give users the capability to define their own workflow and organizations based on the models we provide. Of course, users can only define and modify a certain part of the workflow according to their authorities.

One of the main problems is how to use a more convenient way to help the users (without computer science background) to describe their ideas, and let computers know and implement them. The paper brings forward a solution, and applies that solution in the construction of e-government procurement primarily. We use ontology to build up a domain database. Ontology is a kind of knowledge which can be formalized [22,23]. Therefore, we can use that knowledge to manage knowledge in different domain, and then realize the expression and reuse of knowledge.

We define domain individuals, attributes, operations of objects, and the relation between individuals by using Protégé. Protégé is an ontology model developed by

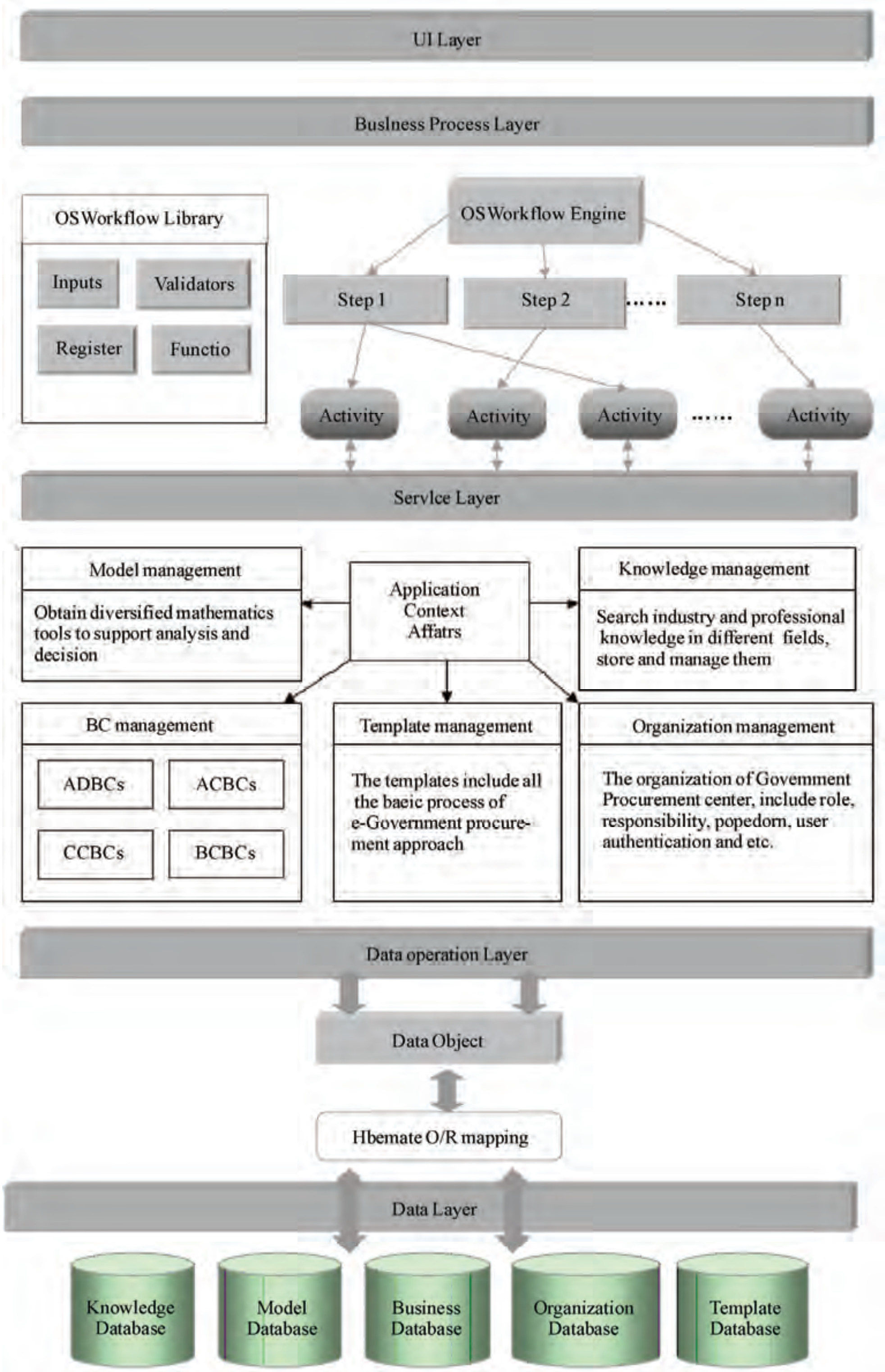

Figure 3. Business component based framework.

Stanford University. It provides a good graphical user interface, and a whole process to compile the figure expression of ontology model, mark and integrate the compiled file, deploy the model and realize application on it at last. It uses OWL as its ontology language by OWL Plug-in component. The Jena [24] component provides

Java API for Protégé.

In this paper, we use Protégé and Osworkflow to do a series of research to realize a prototype of ontology based workflow model.

First of all, ontology of workflow should be described by OWL [23-25]. We take OSworkflow as reference object and design three layers to describe the whole concepts of workflow:

In the first layer, we use OWL to define the concepts of workflow process model and the objects involved, and the Framework of OSworkflow can be seen in **Table 1** [20].

In the second layer, we build extended semantic model for workflow ontology to describe the characteristics of each class [23,25]. OSworkflow provides a comprehensive grammatical structure for each main class [20]; for example, Activity is a sub-class of workflow process, whose attribute set includes activity number, description, user and roles, information and function resource, pre- and post-conditions, rollback attribute, etc. We take ADBCs, ACBCs, BCBCs as prototype to define basic activities and sub-processes. Transition has the attribute set of predecessor and successor link, the transfer type and condition. We use OWL to describe those grammatical structures [22,24].

In the third layer, we design domain ontology of government procurement to describe the abstract classes that are expressed by OWL. The abstract classes are mainly used to describe common characteristics of the domain, which can be used as instances to build up Workflow [26,27]. The domain can be divided into several classes including Roles, Functions, Projects/Products Tables and so on [15,28]. For example, Roles has some common abstract class including suppliers, directors, experts, officials and etc [17]. Different kinds of tables and their characteristics are also described by OWL. The classes contain their basic or common attributes and operations. Detailed information should be provided in the database; for example, we

Table 1. Framework of OSworkflow.

Concept of Workflow	Process of workflow	Template Sub-process(Step) Activity Connector Transition Rules
	Object of workflow	Information Organization Function Resource

should use ontology to describe the user's attributes, the classification of his status, and what kind of operations he should do according to his attributes and status. It is a complicated process.

After building up the ontology of OSworkflow and e-government procurement, we can export the models from Protégé to MySQL to construct ontology database and thus change ontology-based logical relations into relational database [23].

The main purpose to do that is to build the semantic association between OSworkflow, e-government procurement and their Ontology model. Therefore, two aspects of the work should be finished.

First, translate the ontology model into XML expression which can be implemented by OSworkflow. When we import the elements of ontology database into Protégé, the users can use those elements to define, design and modify the existing workflow model in a graphical interface. After they finish their jobs, the protégé will compile the model, and use RMI to output all the information to a java program [23,24]. The java program acts as a translator. First, it identifies the user's role to see if his/her operation is legal, after that, the programs translate the OWL language into XML format and deploy the related file into OSworkflow architecture.

Second, translate the XML format file into OWL language. A typical XML format for OSworkflow to describe the action "apply for procurement" is listed below [20]:

```
<step id="1" name = "Apply for Procurement">
<external-permissions>
<restrict-to>
……
</restrict-to>
</external-permissions>
<actions>
<action id="1" name="Send Applying">
<restrict-to>
<conditions>
<condition type="class">
<arg name="class.name">
com.opensymphony.workflow.util.StatusCondition
</arg>
<arg name="status">Queued</arg>
……
</condition>
</conditions>
</restrict-to>
<results>
<unconditional-result
old-status="Finished"status="Underway"
step="1" owner="${caller}"/>
</results>
</action>……
```


Therefore, to translate the XML is first to find the tags of structure, steps and activities; and then find user, function, condition and others. According to the pre-mapping mechanism, the program can find the related ontology objects in the ontology database to match them, and generate workflow graph by Protégé. The structure of user participation workflow model can be seen in **Figure 4**.

3. Instance

3.1. Domain Analysis of Public Bidding

The most representative approach in e-government procurement is public bidding whose steps can be described below:

First, a demand will be produced such as project construction, government service or a large amount of product procurement.

Second, the government procurement center (GPC) whose work is to help government administrators in different hierarchies to implement their procurement plan would make public bidding file (PBF) according to the demand.

Third, the qualified suppliers would quote price and make bidding file (BF) according to the PBF in finite time.

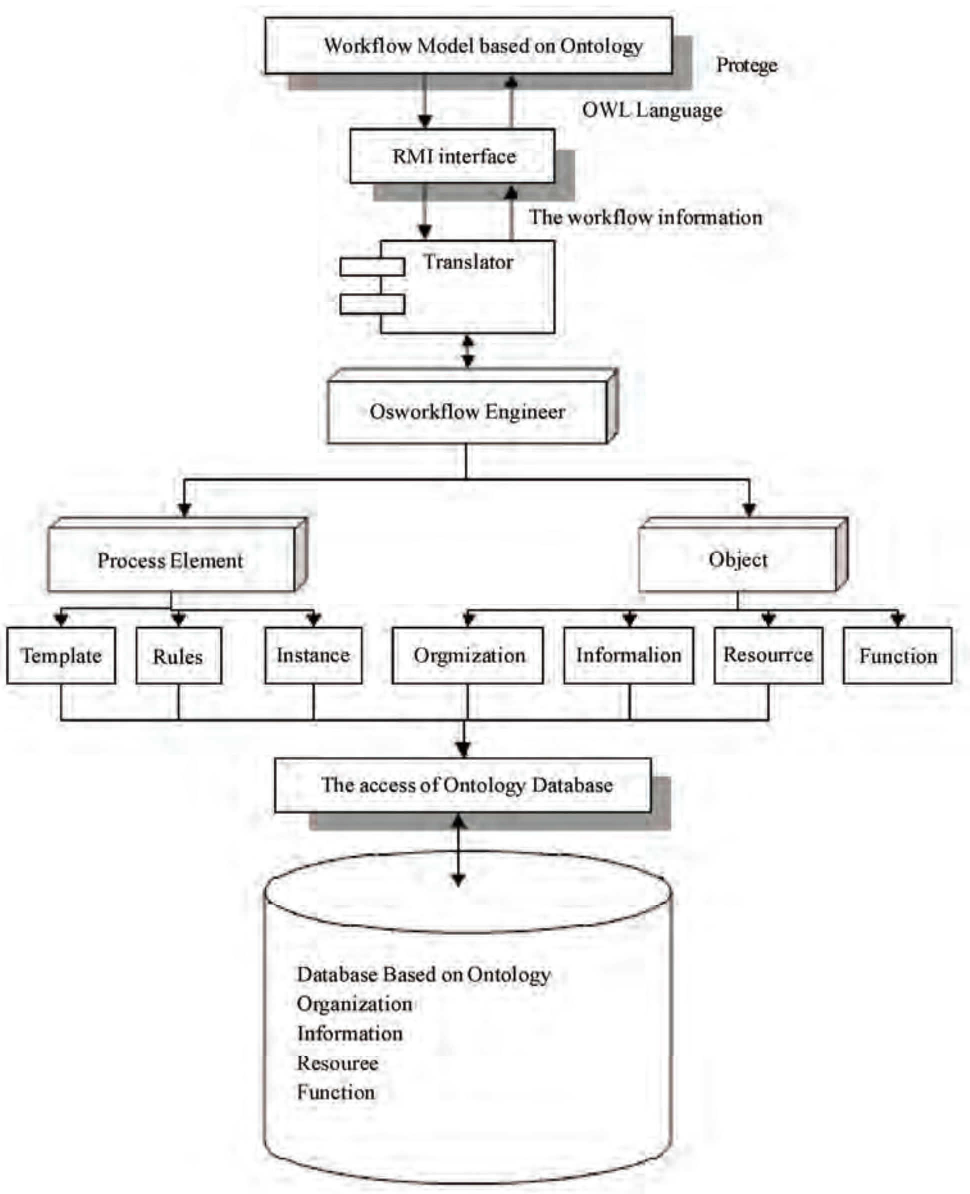

Figure 4. Structure of user participation workflow model.

Fourth, when the bidding is over, the GPC will invite participants and experts together to hold a conference to decide which company or supplier is the most suitable one to charge of the project or procurement plan.

Based on the domain analysis which is studied from FODA, we summarize the main participants and their activities, divide the activities into meta-process and meta-function, at the same time, use DOA method to build data model, and map the data model into information object such as order table [18,19].

3.2. Designing BC Framework and BCs

First, we re-analyze the whole process of public bidding that is executed in twelve different cities in China, abstract common process of public bidding, and compare them with government procurement law in China to find the core processes and functions that can not be modified. Of course, the different parts are also considered as special circumstances to analyze. We use top-down decomposition method to obtain meta-process and metafunction. In order to obtain accurate information to guide the follow work, we consult several university experts and government officials to amend our model.

Second, we divide the model into four parts: decision part, implementation part, supervision part and finance part according to the analysis of their functions and attributes in Section 2. We can design different BCs in different parts. In this paper, we take implementation part as an example to illustrate how to design BCs for government procurement in China.

ADBCs should be designed first, which is the basic procurement process of it. Since it is a process component, it can be divided into many children processes such as applying (P1), auditing application (P2), auditing the authority of suppliers (P3), inviting public bidding (P4), biding (P5), holding the opening bidding meeting (P6), evaluating and publicizing (P7). Each children process can be described as the combination of several meta-process. Furthermore, each meta-process is required by law and has strict regulation of the process. But they are just framework, the concrete realization of process and function should need other BCs' participation.

The paper uses UML activity diagram to describe the business process of public bidding [28], and translates the diagram into XML format that can be identified by Osworkflow.

When we design BCs, we meet the problem that how to confirm the granularity of BCs. In this paper, we learn from reference [7] to build an index system and use entity-append mechanism to evaluate the performance of the BC when adding or reducing a meta-process or meta-function on it. By that method, we can optimize the structure of BCs which are specified by clustering algorithm.

ACBCs can be reused by inherit mechanism, since any new instance of BC can reuse the attributes and functions of ACBCs by extending it. We list representative ACBCs below:

The CRUD of Quotation:
All e-government procurement approaches should have the CRUD operations on quotations, and there are high similarity in the content of all quotations in different procurement approaches, such as price, type, amount and date. The quotation can be shown in many different types, so we use crystal report forms to design an abstract class which contains several different templates of table format that involve all the main government procurement approaches. We can select different types of tables by configuring the parameters in the abstract class. The structure of Quotation BC can be seen in **Figure 5**.

We use Osworkflow to create the model of ADBCs, which uses WorkflowNum [20] to specify serial numbers for each process components and the status management mechanism and trigger mechanism to realize the control of all process. The process can be written in XML format in OSworkflow.

3.3. Integration of Business Component

The design of ACBCs and BCBCs is supported by Spring [19] architecture. First, set unscramble and management tools of configuration file, then initialize ApplicationContext, whose function is to invoke relevant BC according to the information which ServiceBeanFactory supplies. We should also define the event mechanism of the whole architecture that can provide standard such as commit, roll back, throw exception and so on for all the activities. Use IoC to define BC in the configuration file, including the definition, operations, attributes, interface of BC and the Data transmit object [18,19] (DTO) is one of the most important tools in BC architecture, it maps the data into data object in XML format, and transmit them to related BCs which need to handle them.

It can be used in different protocol, language and platform which is suitable for system integration. DTO can be designed by reflection mechanism [18,19], and use public package BeanUtil of apache to transfer data object to java object.

ACBCs encapsulate the common functions or processes that can be reused by all the e-government procurement approach in the domain. Therefore the paper adopts Aspect Oriented Programming (AOP) [16,28] technology and Inherit mechanism to allow other BCs use these ACBCs. The most distinct advantage is that it can reduce coupling degree of the system. If we want to

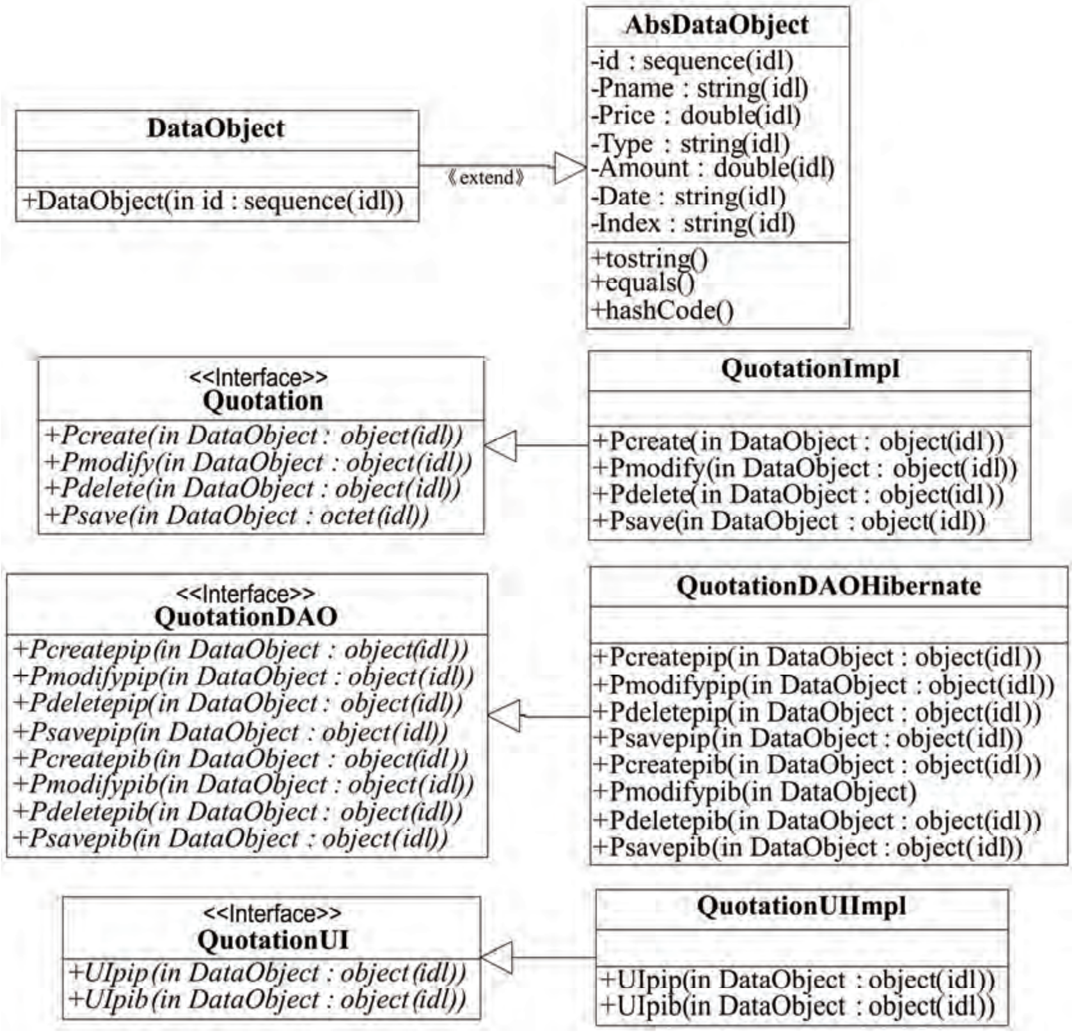

Figure 5. Structure of quotation BC.

modify some common function that is applied in many places of the system, we just need to modify the related ACBC and deploy it and then the modification will be identified and implemented by the whole system.

3.4. Evaluation of System Based on BC Methodology

The system is developed based on an existing open tender system. We redesign the structure of system under the guidance of our framework, decompose the code fragment, and re-integrate them to produce different kinds of BCs, which realize the reuse of existing system.

What's more, ontology is also introduced to design user participation workflow. We mainly make comparisons between the existing system and the new system which is developed under the guidance of our BC framework.

Considering the possible visiting amount of the system, we set the simulative peak visiting amount as 1000 times per minutes, and utilize equation (1) to calculate the respond speed of the server under different visiting amount [22,26,27].

$$T = \frac{1}{P} \tag{1}$$

T: The minimal time unit

P: CPU main frequency

The contents of system test include: the data amount that is stored in the database during the required time (I1), the jump speed between two different processes (I2), the transfer speed of attachment (I3), the refresh speed of the

Table 2. System test results.

RVA	*I* 1	*I* 2	*I* 3	*I* 4
35%	4200	98%	85%	90%
100%	5200	91%	71%	80%

web pages (I4). After hundreds of tests, we find that when the rate of visiting amount and peak visiting amount reaches (PVA) 35%, the speed rate of each index can keep a high value compared with ideal speed. When the rate of visiting amount and peak visiting amount reaches 100%, the speed rate of each index can also keep a good value. The data can be seen in **Table 2**.

Besides, we introduce another two indicators to evaluate the complexity and maturity of the system [22]. The complexity formula can be seen in equation (2) and the maturity formula can be seen in equation (3).

$$C = \frac{N_{r-r} + N_{r-i} + N_{u-u}}{100 \times (N_r + N_u)} \quad (2)$$

$$S = \frac{M_u - (M_c + M_a + M_d)}{M_p} \quad (3)$$

N_r means the number of classes in the system; N_u means the number of web pages in the system; N_{r-r} means the number of relations among different classes, the relationships include inherit and instance; N_{r-i} means the number of the instance relations between class files and web pages. N_{u-u} means the internal relationships among Web pages.

M_p means the final numbers of units that is published and deployed. M_c means the number of new units compared with original design. M_a means the number of the combined or deleted units compared with original design. M_d means the number that is changed or modified compared with original design.

According to [22], we know that if the value of S is larger, the system is more mature; if the value of C is smaller, the system is less complexity. The value of C in public bidding system is 43.38% and S is 73.69%. Compared with the referred existing system, whose value is around 50%, the public bidding system based on BC framework is more superior.

4. Conclusions

First, the paper introduces the development of e-government procurement in China and summarizes both the advantages and deficiencies in recent period. Considering the particulars of e-government, the paper introduces business component theory, and constructs an e-government procurement system framework based on business component. The framework emphasizes process control and provides approach to identify process business components. What's more, we utilize user-participation workflow model based on ontology to realize the flexible design, use Protégé to build ontology model for OSworkflow and e-government procurement, establish semantic association between them and their ontology model.

Meanwhile, the paper also illustrates center management mechanism to manage all the BCs. In order to make the framework more flexible and easy to develop, the framework is divided into 5 layers. Each layer has its BCs. To enhance the reusability of system, the paper introduced 6 different kinds of BCs, and each BC is suit for a particular domain. J2EE light weight development tool is introduced to design the technology architecture of business component framework. At last, the paper takes public bidding as an example to describe how to construct a real system by the knowledge introduced above.

An evaluation test is also exhibited to observe the efficiency of system. The test indicates that enterprise system which is developed by BCs can exhibit more superiority than traditional development method. It is more suitable to be applied in a given domain. The paper also constructs a primary domain BCs library based on ontology for BC management. By those BCs, it realizes the automatic management of the procurement and provides a higher security mechanism to ensure the impartiality, publicity and equity of e-government procurement.

5. Acknowledgment

This research is supported by China National Natural Science Foundation (70971083) and SHUFE Graduate Innovation Foundation (CXJJ-2008-330), Leading Academic Discipline Program, 211 Project for SHUFE (the 3rd phase, 211-5-1), Doctoral Foundation of Ministry of Education (20090078110001).

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J. Service Science & Management, 2010, 3, 309-335
doi:10.4236/jssm.2010.33038 Published Online September 2010 (http://www.SciRP.org/journal/jssm)

A Statistical Analysis to Predict Financial Distress

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Received June11th, 2010; revised July 17th, 2010; accepted August 20th, 2010.

ABSTRACT

The aim of this study is to apply the statistical inference to identify if a firm is likely to become financially distressed in the short term. To do this, we decided to collect data from the firms' financial statements. The analyses performed were based on a group of 45 *financial ratios observed from a sample of* 86 *firms operating in Argentina. First, we used the principal component analysis to turn the information in the* 45 *original ratios into two new global variables named as* Δ*Risk and* Δ*Return. In this way, we can easily represent and compare in a graph the firms' risk and return variations. By the computation of these new variables it is possible to quickly financially categorize a certain firm based on the risk the company has with regard to the nature of its business and the risk involved in the amount of debt it has taken in comparison to the profits that were generated during the last two fiscal years. Second, we performed a logistic regression analysis to estimate the probability that a firm becomes financially distressed in the short term. The model finally selected managed to successfully identify* 85*% of the companies from the sample and it explains* 65*% of the total sample variability. The model is represented by the following variables:* 1) *Current Debt Ratio,* 2) *Total Cost of Debt,* 3) *Operating Profit Margin, and* 4) Δ*ROE. The outcomes from this study are two tools that were developed based on the statistical inference from which we can quickly asses the financial status of a firm based on its risks and return's variation as well as to estimate the probability that a firm becomes financially distressed in the short term. There are different ways of taking these tools into practice such as:* 1) *to control and follow up the financial performance of a company,* 2) *to support the decision of lending money to a company,* 3) *to support the decision of investing money or the decision of merging with a company,* 4) *to support market analysis from a financial perspective, and* 5) *to support actions or decisions related to the financial assessment of a company that declares itself to be financially distressed.*

Keywords: *Financial Distress, Financial Risk, Principal Component Analysis, Logistic Regression Analysis*

1. Introduction

The objective of this study is to identify those companies that have financial problems based on the information contained on their financial statements. With this regard, it is considered that a company has financial problems when it has a high probability of becoming financially distressed in the short term. To do this, we applied the statistical inference to a group of 45 financial ratios observed from a sample of 86 firms operating in Argentina.

In previous similar studies, as for example those proposed by Guzmán [1], Heine [2], De la Torre Martínez [3] or Kahl [4], it was suggested as an objective to find that financial ratio that could better identify a company with financial problems or to find that statistical model that could better predict if a company is financially distressed based on the discriminant analysis. Although all these approaches might be efficient to identify which aspects of a company we should focus on when trying to asses its financial situation, their statistical outcomes would typically not be able to provide a good overview of the firms' overall performance as they are based on just a few variables. This means that with the current statistical models it would be possible to recognize when a company is financially unhealthy but it would be difficult to identify under what circumstances a firm reached that status or even to compare how critical its financial situation is in comparison to other business units or companies within the same industry. Moreover, most of the statistical studies in the current literature do not take into consideration the variation of the firms' financial ratios through the last fiscal periods. Instead they provide a financial diagnosis based on the most recent snapshot of the firms' situation, which might result in wrong decisions being made.

In an attempt to provide a financial study that can cover the issues previously discussed, we decided to combine two statistical analyses with the aim of developing a set of tools that will provide a comprehensive and accurate financial diagnosis of a firm that can be used to take decisions within different business scenarios such as investments analysis, credits offering, and financial management, among others. In this way, we first used the principal component analysis to turn all the data initially collected into two new variables. With this analysis we can obtain a financial overview of a certain firm and we can represent and compare its financial situation based on the risk the company has with regard to the nature of its business and the risk involved in the amount of debt it has taken in comparison to the profits that were generated during the last two fiscal years. Second, we used the logistics regression analysis to precisely determine when a firm has financial problems and to identify those ratios that have a higher influene on its financial condition.

The rest of this paper is organized as follows. In Section 2, we present the sample design by defining its size and composition as well as the criteria used to collect all the data from the firms' financial statements. In Section 3, we define the group of 45 financial ratios that were computed for each company in the sample. In Section 4, the principal component analysis is performed to turn the information contained in the 45 original ratios into a small group of 2 new variables named as Δ*Risk* and Δ*Return*. In Section 5, we developed different logistic regression models to estimate the probability that a firm becomes financially distressed in the short term. In Section 6, the tools developed from the principal component and the logistic regression analyses are applied to a new sample. The objective in this case is to evaluate the joint effectiveness of these tools to recognize those companies with financial problems. Finally, the conclusions of the present study together with its possible uses are described in Section 7.

2. Sample Design

A very important aspect in this kind of statistical research is the sample design from which the statistical models will be developed. For example, if we consider a sample of companies that belong to the construction sector then the resulting statistical model can only be applied to companies of that sector. Also, if the sample is composed by 90% of companies that did not have any financial problems and only 10% of companies that were financially distressed then the capacity of any resulting statistical model to discriminate companies with financial problems will not be significant. Because of these reasons, below we comment all the criteria considered to design the sample which will determine the scope of the analysis.

The sample is composed by 86 firms that operate in Argentina, from which 43 did not have any financial problems (group 1) and the other 43 were financially distressed during the period under analysis (group 2). See Appendix 1 for a complete sample description.

All the information considered in the present study was obtained from the financial statements of each company. In the case of those companies that did not have any financial problem, the financial statements were obtained from the *Bolsa de Comercio de Buenos Aires* (*BCBA*). For those companies that had financial problems, the financial statements were obtained from the official reports made by the corresponding receivers that are published by the *Cámara Nacional de Apelaciones en lo Comercial*.

Different authors from statistical books consider valid to collect at least information from 5 observations for each variable that is included in the statistical model. William Beaver [5] and Edward Altman [6] carried out similar statistical analysis working with a sample of 120 and 60 companies, respectively. In both cases, significant results were obtained and they both considered different models with no more than 5 variables. Therefore, based on these results and considering that in the present study we will not develop any model with more than 5 variables, we can state that a sample of 86 firms is big enough to carry out any statistical analysis.

With regard to the proportion of companies in the sample with and without financial problems, it is not strictly necessary to consider the same amount of observations for each of these groups. However, this is recommended to obtain a better representation of the mean and the deviation of the variables observed in each group. To better understand this issue, we can consider the extreme case of a sample with 1 company that did not have any financial problems and 99 companies that were financially distressed. Based on this sample, when it comes the moment to estimate the probability that a firm becomes financially distressed it is reasonable to think that the corresponding model will have a clear tendency to classify any company as if it is going to have financial problems in the near future. This is because the sample, while not being representative from the population, does not "reveal" the different ways in which a company without financial problems can be found. In other words, the sample contains very little information about the behavior of the variables observed in companies without financial problems, and therefore, it is more difficult for the model to recognize companies from this group.

Another important aspect to consider is the period of time from which the information in the financial statements is collected, especially in the case of those companies that had financial problems. With this regard, the sample considered in the present study includes information from companies that operated during the years 2003, 2004, and 2005. It is important to notice that if this period is too long, for example more than 10 years, then we would run the risk of mixing the financial information from companies that operated in different macroeconomic contexts. If that is the case, then the interpretation of any financial information should be done individually even for companies that operated in the same sector. In countries that have a stable economy, this effect would not introduce a high distortion in the data collected. However, this is not the case of Argentina. In addition, we should notice that it was decided not to include any financial information from companies that had financial problems during the years 2001 and 2002 because during that period there was an economic crisis that affected the normal operations of companies. In this way, we avoid to include in the present analysis any atypical variations that are not the object of study and that could bring distortions into the analysis. We should notice that only for a few companies we decided to consider the financial information from 2002 to be able to compute the variation of some financial ratios over two consecutive periods. In any case, the effect of introducing this information in the study is not significant because in 2002 the amount of companies that had financial problems was significantly lower in comparison to 2001 when the economic crisis was originated (see **Figure 1**).

In the case of those companies that had financial problems, the required information for the statistical analysis was obtained from the financial statements that correspond to the period during which each company was financially distressed and from the previous period. In this way, we can include in the analysis the evolution of some financial ratios from one period to another. In the case of those companies that did not have any financial problems, the required information was obtained from the financial statements of two consecutive periods, always within the period under analysis of the present study.

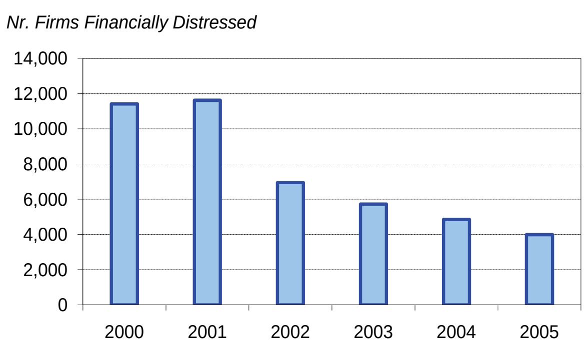

Figure 1. Yearly number of firms financially distressed in Argentina.

In similar researches, it was decided to include in the statistical analyses financial information until five periods before the companies were financially distressed. However, these studies analyzed the information from each period separately instead of including in one sample some variables that reflect the evolution of the ratios over two or more periods. The methodology used in these analyses consisted in using the financial information from previous periods as a separate sample to test the discrimination power of a certain statistical model. This model was developed through a group of financial ratios that correspond to the most recent period during which each company was financially distressed. As expected, the results obtained show that as long as the financial information in a sample was more far away in time from the period in which the company was financially distressed then the capacity of the model to distinguish between companies with and without financial problems was diminishing. Therefore, it can be concluded that it is not relevant to include in the analyses financial information from many periods before the companies become financially distressed. This is because by that time companies might show a good financial performance and if this information is taken into account then it will reduce the capacity of the model to distinguish those companies with financial problems. In this sense, it seems more reasonable to focus our attention on the information from those periods where the characteristics of the financial problems become evident in a company, *i.e.* some years before they become financially distressed.

The companies included in the sample belong to different economic sectors such as industry, commerce, agriculture, and services. The main reason of this choice is to develop a broad statistical model that can be applied in different type of companies.

The financial theory states that it is not convenient to directly compare the financial ratios from two companies that belong to different economic sectors. This is because the economic dynamics in these sectors might differ substantially. For example, a financially healthy company that operates in a certain sector can show a liquidity ratio of 2 while other company that performs a different type of activity can have the same value of this financial ratio and be in financial problems. Therefore, from this perspective it seems not reasonable to include in the sample companies that perform different economic activities. This is because the sample could contain misleading information with regard to those characteristics that allow identifying a company with financial problems, *i.e.* the relation between the financial ratios and the financial distressed could be distorted. However, we should consider that we are performing a multivariate analysis, and therefore, the characteristics that are observed in each individual are compared in a simultaneous and global way. In this way, it is more difficult that the particular behavior of certain ratios in some economic sectors affect the global profile of a company. Nevertheless, there are two precautions that can be implemented in order to diminish the effect that some characteristics inherit to each economic sector have in the identification of companies with financial problems. The first precaution consists of including in both groups of the sample companies from the same economic sectors. The second precaution consists of having the same amount of companies from each economic sector in both sample groups. Although the second precaution was not implemented for all the economic sectors because of the difficulties to find available financial data, the sample was design to keep the highest balance possible in both groups.

William Beaver [5] designed a paired sample based on companies that operated in different economic sectors. In that sample, for every company that had financial problems there was another financially healthy company from the same economic sector, and whenever it was possible, with the same size. With this regard, we should notice that the size of a company was measured through its total assets. In this way, Beaver performed a univariate statistical analysis, *i.e.* that the financial ratios of each company were compared once at a time and that the distinction of those companies with financial problems was made through a single ratio with a cut-off value.

In his research, Beaver suggested doing a *paired analysis* with the objective of quantifying the effect that the economic sectors and the size of the companies have in the identification of those companies financially distressed. In this way, for each pair of companies from the same economic sector and with similar sizes the difference of each financial ratio was computed. Afterwards, these differences were evaluated to determine if there was sufficient statistical evidence that allowed the identification of companies with financial problems. We should notice that because each difference of the financial ratios was determined based on companies from the same economic sector and with similar sizes, the effects of these factors in the sample were mitigated. In addition, it is important to mention that these differences were only computed to quantify the impact that the economic sectors and the size of the companies have on the identification of those companies with financial problems. However, to classify each firm in one of the two groups a limit value from a single financial ratio was considered. This limit value was computed through a direct comparison of the financial ratios, *i.e.* no differences between the financial ratios were considered. The reason of this is that it is not possible to get any conclusions from a single individual through a paired analysis because always two companies are compared at the same time.

Once the paired analysis is performed, the capacity of each financial ratio to identify those companies with financial problems can be compared to those capacities that are obtained from a statistical analysis based on a global comparison of the companies. With this regard, one would expect these results to be similar as long as the effect of the economic sectors and the size of the companies were negligible. In fact, the findings from Beaver's research support this statement. Therefore, everything seems to indicate that using a paired sample is the best approach to mitigate the possible effects from the economic sectors and the size of the companies. However, we must take into account that the research made by Beaver was based on a univariate statistical analysis, and therefore, each financial ratio was compared once at a time. This means that the effects of these factors when multiple financial ratios are compared at the same time were not evaluated. In this sense, we expect that by simultaneously comparing multiple financial ratios the effects of the economic sectors and the size of the companies should also be mitigated. Therefore, we can conclude that it is not strictly necessary to have a paired sample to continue with our study although keeping a certain balance in the sample can help to diminish the undesired effects of the economic sectors and the size of the companies.

Another precaution that has been considered in the present study to facilitate the identification of companies with financial problems in different economic sectors is the incorporation of a variable that measures the performance of a given company in comparison to the average performance of the sector. More details about the variables considered can be found in the following section.

Finally, another important aspect to be considered in the sample design is the size of the companies. This aspect has already been mentioned when referring to Beaver's research. With this regard, the sample was designed not to include companies with high assets value, *i.e.* all the companies included in the statistical analysis have assets lower than 500 [Million $AR]. The reason of this is that there are just a few cases where big companies suffered financial problems, and therefore, it is reasonable to think that these firms belong to a different statistical population. With this regard, Alexander Sydney [7] suggests that there is theoretical evidence as well as empirical facts that demonstrate that the return rate of a company becomes more stable as the size of its assets increases. This could imply that a firm with a high assets value would have a lower risk of becoming financially distressed in comparison to a middle size or small company even when they both show the same financial ratios values. As a result of this, we could first think that it is not convenient to compare the financial ratios of two companies that differ significantly in its size. Therefore, considering that a consistent statistical analysis requires that all the sample observations come from the same population, we have decided to include companies within a similar range of the assets value in the two sample groups considered. Nevertheless, it is not desirable to have a perfect homogeneity in the sample with regard to the size of the firms because this would decrease the ability of the model to identify those companies with financial problems.

3. Variables Considered

The selection of the variables that afterwards are going to be used to carry out the statistical analysis is a very important stage of this study. The reason of this is that at this moment we should take into account all those aspects from the companies that we think they could have some relationship with the fact that these firms become financially distressed. In this sense, the selections of the variables together with the sample design define the scope and the applicability of this research. To select the variables considered in this study the following criteria was considered: 1) popularity of some ratios in the financial literature and 2) the performance of some financial ratios in similar statistical analysis.

The statistical analyses presented in the following sections consider a total of 45 variables. The values of each of these ratios were computed for every firm included in the sample based on the criterias described in the previous section. In Appendix 2, we present a list with all the formulas describing each ratio. In order to have a better representation of the selected ratios, we have decided to group them based on the following categories: 1) Liquidity Ratios, 2) Operating Efficiency Ratios, 3) Business Risk Ratios, 4) Financial Risk Ratios, 5) Return Ratios, and 6) Growth Ratios. It should be noted, that we have included a new financial ratio named *Benchmarked Return*, with the aim of having a measurement that compares the return of each company against the average return of the sector that represents that company. In Appendix 3, we provide the average return considered for each sector that was used to calculate this new ratio.

We should notice that in this particular study we have considered a high number of explanatory variables in order to obtain a comprehensive data base that allow us to develop and compare multiple regression models. Moreover, because we are implementing a principal component analysis there is no need to reduce the number of variables considered in the study, especially if many of them are correlated.

4. Principal Component Analysis

In this section, we present the results obtained after applying the principal component analysis to the data collected in the sample. To compute the principal components we followed the procedures proposed by Peña [8] and Johnson [9].

After calculating the eigenvalues from the covariance matrix **C**, we can see that the first two eigenvalues stand for 93% of the total variance (see Appendix 4). Because of this reason, it was decided to work with the first two principal components F_1 and F_2 to represent the sample data. We should notice that these results are significant considering that we managed to reduce the space of representation of the data set from 45 variables to a two dimensional space.

To represent each of the companies from the sample in a unique graph, we calculated the values that each of the principal components take for each firm (see Appendix 5). To do this, we first determined the eigenvectors matrix **V**. The results obtained are shown in **Figure 2**. We have represented in blue color those firms corresponding to group 1 (without financial problems) and in red color those firms from group 2 (with financial problems). This representation excludes two *outliers*, *i.e.* observations with particular characteristics that deviate from the rest of the sample. We have decided not to consider these outliers to avoid that the scale of the graph is set in such a way that the rest of the companies cannot be distinguished.

Although it seems that there is not a clear distinction between the two groups, the firms from group 2 tend to have higher values of the principal component F_2 in comparison to the firms of group 1. In addition, we can observe a great concentration of companies with a similar negative value of the component F_1 as well as some spread observations from both groups that present higher

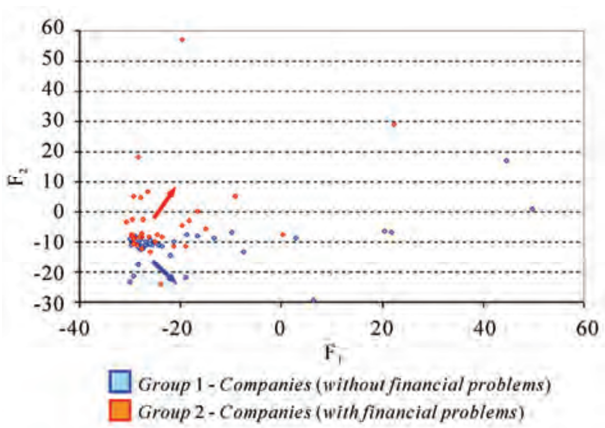

Figure 2. Representation of the firms based on the principal component values without considering the outliers.

values of this component.

To continue with the principal component analysis, the correlation between the original 45 variables and the selected principal components were computed.

The results obtained indicate that the principal component F_1 has a high positive correlation with the following variables: X_{14} – Operating Leverage, X_{41} – ΔDebt Coverage, and X_{42} – ΔOperating Profit Margin. This suggests that F_1 reflects two types of risks: 1) the risk that a company has based on how much money it has generated to cover its debt, and 2) the risk of the company's business based on the impact that the sales variations have on the company's profits. Therefore, we have decided to name this principal component as ΔRisk.

A high value of F_1 can be caused by: 1) a high operating leverage, 2) an improvement of the debt coverage, 3) an improvement of the operating profit margin, or 4) a combination of all these alternatives. Nevertheless, we should keep in mind that based on the eigenvectors matrix the variable X_{14} – Operating Leverage is the one with a higher influence over F_1. In this way, we can conclude that those companies that have high values of this principal component will most probably present a high leverage supported by an improvement of the debt coverage and the operating profit margin. With this regard, if we have a look at **Figure 3** we can see that those firms that present high values of F_1 with a value of F_2 similar to the sample average show the characteristics previously mentioned. In addition, we should consider those firms that present a high value of F_1 together with a high value of F_2. In these cases, we could verify that the corresponding companies present a strong decrease in the debt coverage as well as the operating profit margin. Consequently, the high value of F_1 is exclusively due to a high value of the operating leverage.

To summarize the analysis so far, we can state that the firms with a high ΔRisk (F_1) only show an improvement of the debt coverage and the operating profit margin

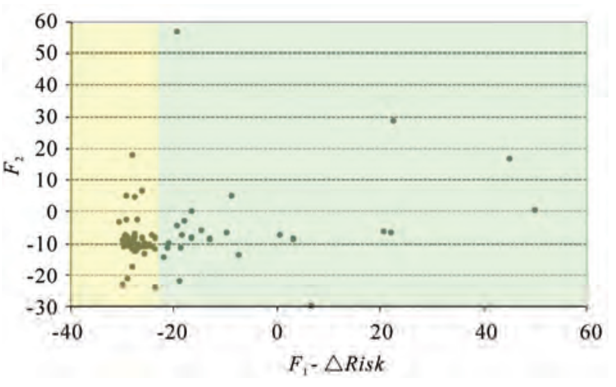

Figure 3. Categorization of the firms based on the values of F_1 – ΔRisk.

when they have a value of F_2 similar or lower to the sample average. In addition, those companies that have high values of both principal components show a high variation of their operations together with a decrease in the debt coverage and the operating profit margin. Therefore, we would expect that a firm with financial problems would show the latter characteristics although these are not sufficient conditions to classify a firm as financially distressed. This means that a company with a negative value of the ΔRisk (F_1) does not necessarily need to have financial problems. In other words, those companies that have higher risks in combination with good profits can be considered as financially healthy while those companies that have higher risks but show poor profits will most probable have financial problems in the short term.

In **Figure 3**, we represent how the firms included in the sample can be differentiated based on the values of F_1. The yellow bandwidth includes a big amount of companies with a low value of the operative variation while the green bandwidth corresponds to a few companies with a high value of the operative variation. Considering that firms from group 1 and 2 show low and high values of F_1, it is difficult to distinguish those companies with financial problems by only having a look at this principal component. However, if we combine this information together with the analysis of F_2 then we will find out that it is possible to recognize certain characteristics from the companies based on the principal components representation.

If we now consider the principal component F_2, we see that it has a high negative correlation with the following variables: X_{33} – ΔNet Income, X_{43} – ΔNet Profit Margin, and X_{45} – ΔROA (see Appendix 6). In this way, we can conclude that this component is mainly reflecting two aspects: 1) the changes in the ability of a firm to generate revenues, and 2) the changes in the efficiency of a firm to generate revenues. This is the reason why it was decided to name the component F_2 as ΔReturn.

A high value of F_2 can be caused by: 1) a decrease of the net income, 2) a decrease of the net profit margin, 3) a decrease of the return on assets, 4) a combination of all these alternatives. This means that those companies with a high value of this component would most probably show a deterioration of their return. In fact, if we have a look at **Figure 2** we can see that most of the firms with a high value of F_2 belong to group 2, *i.e.* that these companies have had financial problems. In addition, we can see from **Figure 2** a small number of firms that show a low value of F_2 although they belong to group 2 as well. Therefore, in these cases we could conclude that the corresponding companies are actually recovering from their financial problems by showing an improvement of their returns.

In **Figure 4**, we represent how the firms included in the sample can be differentiated based on the values of F_2. The red bandwidth includes those companies that have shown a high deterioration of their returns while the green bandwidth corresponds to those firms that have shown an improvement in their returns. In addition, we have defined a yellow bandwidth that corresponds to those companies that show a similar value of their ΔReturn that approximates to the sample average.

After performing an analysis of each principal component, we can now combine all the information obtained to define different clusters that can help us to identify the status of a certain firm with regard to its ΔRisk and ΔReturn. This classification of the sample is represented in **Figure 5** together with a description of the type of evolution that a company belonging to a certain sector has suffered.

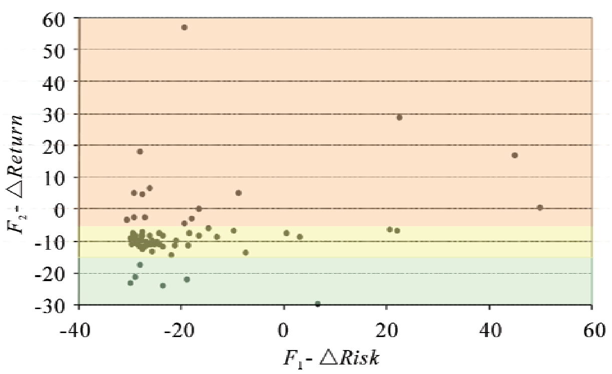

Figure 4. Categorization of the firms based on the values of F_2 – ΔReturn.

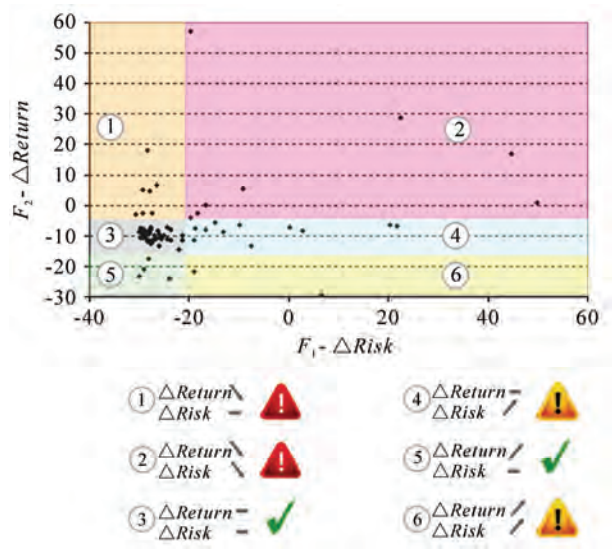

Figure 5. Categorization of the firms based on the principal components.

We would expect those firms with a higher disposition to have financial problems in the short term to fall into sectors 1 or 2. The sector 1 corresponds to firms showing a significant deterioration on their returns while sector 2 represents companies showing higher risks in combination with a deterioration of their returns. In a similar way, we would expect those firms with a low disposition to have financial problems in the short term to fall into sectors 5 or 6. The sector 5 corresponds to those companies that show signs of stability, low risk and return improvement. In a similar way, the sector 6 is represented by companies that show a significant return increase in combination with higher risks. In the case of sectors 3 and 4 it is not possible to link them to any of the groups considered, *i.e.* that for those companies falling into these sectors we are not able to make any conclusions with regard to their disposition of having financial problems in the near future. We could say that these companies have a financial situation similar to the sample average. However, we should keep in mind that those companies within sector 4 have higher risks in comparison to those firms from sector 3.

To summarize, we have seen that the results obtained after performing the principal component analysis indicate that this technique has been very useful to achieve a better representation of the firms, especially considering the power of synthesis that it brings by compiling the information contained in the 45 original variables into only 2 new components. By the computation of these new variables it is possible to quickly financially categorize a certain firm based on the risk the company has with regard to the nature of its business and the risk involved in the amount of debt it has taken in comparison to the profits that were generated during the last two fiscal years. In this way, depending on the sector to which a company belongs to it is possible —in some cases— to make an inference with regard to the disposition of this firm to have financial problems in the short term. In the next section, we will perform a logistics regression analysis to develop a statistical model that allows us to estimate the probability that a firm becomes financially distressed in the short term. In this way, we will be able to compute a new quantitative measure that will help us to identify those firms with financial problems.

5. Logistics Regression Analysis

Because the principal components F_1 – ΔRisk and F_2 – ΔReturn have been useful to represent the firms from the sample and because they hold 93% of the total variance from the 45 original variables included in the analysis, it would be reasonable to use these components to build a logistics regression model. To do this we followed the procedures proposed by Hosmer and Lemeshow [10].In this way, this model would allow us to estimate the probability that a firm becomes financially distressed in the short term, which in the end could be used as a quantitative measure to help us to identify those companies with financial problems. However, the results obtained from the model validation based on the coefficients of determination indicate that the model only explains a small percentage (31.87%) of the behavior of the dependant variable we are trying to estimate: Y – Financial Distress ($Y = 1$ if the firm IS financially distressed, $Y = 0$ if the firm is NOT financially distressed). Therefore, we decided to further investigate if it is possible to find a regression model that can better adjust to the data collected.

If we keep in mind that the principal components are actually a linear combination of the 45 ratios considered in this study, we could then make the following question: What would happen if we develop a regression model only with those ratios that are representative of each principal component? The reason of this question is that the variance of each principal component can be negatively affected by the values of some ratios that are not useful to identify those firms with financial problems. This does not mean that the regression model based on the principal components is useless but it brings the opportunity of finding a new model that better explains the behavior of the firms in the sample.

To answer our question, we decided to build a new regression model based only on those ratios that have a medium or high correlation with the principal component F_2 – ΔReturn. In this case, the result obtained from the model validation indicates that this group of ratios can explain 35.63% of the variance of the dependant variable Y – Financial Distress. In this way, we verified the idea that the new model is more efficient to identify those firms with financial problems in comparison to the principal components model. This is because we can obtain similar results but with much more less information. Therefore, following this reasoning, we can state that although the principal components analysis has been useful to represent companies with different financial profiles it is not effective to use these results in a regression model. In fact, we have demonstrated that with a few ratios we can develop a model that manages to identify a similar percentage as the model based on the principal components, which contains data collected from all the 45 ratios.

To summarize, we have demonstrated that in this particular study it is difficult to combine the principal component and the logistic regression analyses. This situation brings us a new problem. It might be the case that there are some ratios that are effective to estimate the probability that a firm becomes financially distressed in the short term but that they have a low correlation with the principal components. To solve this problem, it was decided to carry out a global analysis that contemplates the 45 financial ratios included in this study.

It is clear that if we consider all the possible combinations that can be obtained based on the 45 ratios to develop a regression model with no more than 5 variables then it would be very hard to evaluate and compare all these alternatives by trial and error. Because of this reason, we decided to implement a methodology that allows us to reduce the number of models to be compared. This methodology consists in focusing our attention on the first 22 ratios with the highest coefficient of determination based on a regression model with a single independent variable. In this way, the objective is to develop different models only with those variables that by themselves are more effective to identify those firms with financial problems. It is important to keep in mind that this methodology does not guarantee an optimal solution. This is due to the fact that a certain ratio can show a low R^2 in a regression model with a single independent variable but when it is combined with other ratios then the information that brings to identify those firms with financial problems can be much higher. Nevertheless, the methodology implemented is still a valid procedure to find a near optimal solution especially if we consider the high amount of ratios included in the analysis and that many of these variables are correlated.

In **Table 1**, we present the ranking of the coefficients of determination. From these results, we can see that those variables that had a higher correlation with the principal components are spread all over the ranking. However, we should notice that most of the ratios that are correlated with the component F_2 have a R^2 higher than 0.1. This could be explained by the fact that the parameter value from the component F_2 in the regression model is higher than the component F_1. In addition, it is important to mention that most of the ratios that can better individually explain the behavior of the firms are related to profitability and return aspects.

Based on the first 22 ratios shown in **Table 1**, a total of 57 regression models were tested (see Appendix 7). We should notice that we have not included the outliers identified in the principal component analysis when developing any of these logistics regression models. We limited each model to 5 independent variables at most. In addition, the ratios were first grouped based on their correlations to avoid including in the same model more than one ratio that brings the same type of information. For example, it is not reasonable to include in the same regression model only ratios related to liquidity aspects given that we would miss some important financial information from the companies related to aspects such as operational performance, debt, profit, and growth.

The models tested were compared based on the value

Table 1. Ranking of the coefficients of determination for a regression model based on a single financial ratio.

Independent Variable		R^2	Independent Variable		R^2
X_{29}.	ROA	0.3687	X_{40}.	ΔDebt Turnover	0.0596
X_{27}.	Return on Capital Employed (ROCE)	0.3116	X_{11}.	Current Assets Turnover	0.0429
X_{25}.	ROE	0.3088	X_{8}.	Average Inventory Processing Period	0.0378
X_{44}.	ΔROE	0.2505	X_{35}.	ΔFixed Assets Ratio	0.0369
X_{24}.	Net Profit Margin	0.2386	X_{36}.	ΔWorking Capital	0.0335
X_{43}.	ΔNet Profit Margin	0.2326	X_{6}.	Average Receivables Collection Period	0.0334
X_{26}.	Benchmarked Return	0.2258	X_{42}.	ΔOperating Profit Margin	0.0332
X_{16}.	Current Debt Ratio	0.2242	X_{14}.	Operating Leverage	0.0233
X_{15}.	Total Debt Ratio	0.2236	X_{10}.	Total Assets Turnover	0.0226
X_{23}.	Operating Profit Margin	0.1977	X_{38}.	ΔTotal Assets Turnover	0.0198
X_{45}.	ΔROA	0.1894	X_{18}.	Non-Current Debt Ratio	0.0127
X_{19}.	Equity to Debt Ratio	0.1885	X_{22}.	Gross Profit Margin	0.0102
X_{32}.	ΔAssets	0.1762	X_{7}.	Payables Payment Period	0.0101
X_{2}.	Working Capital Ratio	0.1672	X_{12}.	Fixed Assets Turnover	0.0093
X_{33}.	ΔNet Income	0.1642	X_{37}.	ΔCurrent Ratio	0.0056
X_{3}.	Current Ratio	0.1627	X_{1}.	Fixed Assets Ratio	0.0053
X_{20}.	Debt Coverage	0.1502	X_{41}.	ΔDebt Coverage	0.0053
X_{5}.	Cash Ratio	0.1464	X_{31}.	ΔSales	0.0038
X_{21}.	Total Cost of Debt	0.1110	X_{9}.	Cash Conversion Cycle	0.0037
X_{39}.	ΔTotal Debt Ratio	0.1037	X_{28}.	Operating Return on Capital Employed	0.0028
X_{30}.	Operating Profit on Assets	0.1026	X_{13}.	Equity Turnover	0.0008
X_{17}.	Debt Turnover	0.1003	X_{4}.	Quick Ratio	0.0003
			X_{34}.	ΔLiabilities	0.0003

of the different coefficients of determination. We should notice that usually when some liquidity ratio was included in a certain model then the corresponding estimated parameter was not coherent with the expected behavior of that variable. In other words, we found out that in many of these models a higher liquidity implied a higher probability of the firm becoming financially distressed, which is not coherent with the observed behavior of this variable. This is the reason why some models had to be ignored even when they presented high values for the coefficient of determination.

In **Table 2** we present the ratios that belong to the regression model selected as the output for this analysis. This model was mainly selected based on the value of the coefficient of determination but also based on the coherence of the estimated parameters with the expected behavior of each variable as well as the author's judgment with regard to the relevance of the different ratios considered.

To develop this model, we estimated the corresponding parameters through three different methods: 1) least squares, 2) weighted least squares, and 3) maximum likelihood. The results obtained are summarized in **Table 3**.

Table 2. Variables included in the regression model selected.

Symbol	*Name*	*Type of Variable*
X_{16}	*Current Debt Ratio*	Independent and Continue Variable
X_{29}	*ROA*	Independent and Continue Variable
X_{21}	*Total Cost of Debt*	Independent and Continue Variable
X_{23}	*Operating Profit Margin*	Independent and Continue Variable
X_{44}	*ΔROE*	Independent and Continue Variable
Y	*Financial Distress*	Dependent and Dicotomic Variable

Table 3. Estimation of the regression model parameters.

	Estimated Parameter					
Estimation Method	**b_0**	**b_1 (X_{16})**	**b_2 (X_{29})**	**b_3 (X_{21})**	**b_4 (X_{23})**	**b_5 (X_{44})**
Least Squares	−2.6012	2.4251	−9.0192	13.3503	−3.1242	−0.2422
Weighted Least Squares	−1.3466	1.4257	−0.2317	7.5672	−1.3062	−0.2490
Maximum Likelihood	−2.2748	2.1978	−2.4296	12.3765	−2.7072	−0.2648

Considering that many of the validation tests for the regression model require that the parameters were estimated through the maximum likelihood method then we are going to keep these results as representative of the model. In this way, the regression model is defined through the following expression:

$$\hat{Y} = \frac{1}{1 + e^{-(-2.2748 + 2.1978X_{16} - 2.4296X_{29} + 12.3765X_{21} - 2.7072X_{23} - 0.2648X_{44})}} \quad (1)$$

where $\hat{Y}$ represents the probability that a firm becomes financially distressed in the short term. From this model, we can see that an increase of the current debt ratio or an increase of the total cost of debt implies a higher probability for a company to become financially distressed. In addition, an increase of the ROA, an increase of the operating profit margin, or an increase of the ROE determines a lower probability of a firm to become financially distressed in the short term. In this way, we can verify that the estimated values of the parameters are coherent with the expected financial impact that these ratios should have on a firm.

As a next step, we performed different tests to validate the logistics regression model obtained as suggested by García [11]. We should notice that in all these validation tests we have considered a significance level of 5%.

The first validation test corresponds to the following hypothesis: H_0) *the model fits the data*. To perform this validation, we determined the corresponding statistics through the following expressions:

$$\chi^2 = \sum_{t=1}^{n} \frac{\left[Y_t - \pi\left(\bar{X}_t\right)\right]^2}{\pi\left(\bar{X}_t\right)\left[1 - \pi\left(\bar{X}_t\right)\right]} \quad (2)$$

$$D = -2Ln\zeta \quad (3)$$

The results obtained are shown in **Table 4**. We can see that the hypothesis considered is not rejected, and therefore, we do not have enough statistical evidence to prove that the model does not fit the data.

The second validation test corresponds to the following hypothesis: H_0) $\beta_1 = \beta_2 = \cdots = \beta_k = 0$. In this case, the corresponding statistic was determined through the following expression:

$$G = 2(Ln\zeta - Ln\zeta_0) \quad (4)$$

The results obtained for this validation test are shown in **Table 5**. Considering that the hypothesis is rejected then we have enough statistical evidence to state that at least one of the estimated parameters in the model is not null.

To continue with the model validation, we performed the significance tests of the estimated parameters. The results obtained through the Wald and Wilks methods are shown in **Table 6**.

These results indicate that there is not enough statistical evidence to state that the estimated parameters for the variables X_{16} – Current Debt Ratio and X_{21} – Total Cost of Debt are null. In the case of the variables X_{23} – Operating Proft Margin and X_{44} – ΔROE, the Wald validation method indicates that there is enough statistical evidence to think that the corresponding estimated parameters are null. However, when we consider the Wilks method the results obtained are the opposite. Therefore, to decide if these variables should be included in the model we decided to calculate the maximum probabilities of rejecting the hypothesis H_0) $\beta_4 = 0$ and H_0) $\beta_5 = 0$ when they are actually true. These probabilities are $\alpha_4 = 0.1448$ and $\alpha_5 = 0.0871$, respectively. In this way, given that

Table 4. Validation results for H_0) *the model fits the data*.

Hypothesis	H_0) *The model fits the data*	
Statistic Computed Value	$\chi^2 = 49.0968$	$D = 60.8275$
Critical Value	$\chi^2_{80;095} = 108.6479$	$\chi^2_{80;095} = 108.6479$
Rejection Condition	$\chi^2 \geq \chi^2_{80;095}$	$D \geq \chi^2_{80;095}$
Result	***Do Not Reject***	***Do Not Reject***

Table 5. Validation results for H_0) $\beta_1 = \beta_2 = \cdots = \beta_k = 0$.

Hypothesis	H_0) $\beta_1 = \beta_2 = \cdots = \beta_k = 0$
Statistic Computed Value	$G = 58.3938$
Critical Value	$\chi^2_{5;095} = 11.0705$
Rejection Condition	$G \geq \chi^2_{5;095}$
Result	***Reject***

Table 6. Validation results for the significance tests of the estimated parameters.

	Estimated Parameters				
Wald Method	**b$_1$ (X$_{16}$)**	**b$_2$ (X$_{29}$)**	**b$_3$ (X$_{21}$)**	**b$_4$ (X$_{23}$)**	**b$_5$ (X$_{44}$)**
Hypothesis	$H_0)\ \beta_1 = 0$	$H_0)\ \beta_2 = 0$	$H_0)\ \beta_3 = 0$	$H_0)\ \beta_4 = 0$	$H_0)\ \beta_5 = 0$
Statistic Computed Value	$t = 2.2064$	$t = -0.5036$	$t = 1.6817$	$t = -1.0661$	$t = -1.3713$
Critical Value	$t_{80;0.95} = 1.6641$	$t_{80;0.95} = 1.6641$	$t_{80;0.95} = 1.6641$	$t_{80;0.95} = 1.6641$	$t_{80;0.95} = 1.6641$
Rejection Condition	$t \geq t_{80;0.95}$	$t \leq -t_{80;0.95}$	$t \geq t_{80;0.95}$	$t \leq -t_{80;0.95}$	$t \leq -t_{80;0.95}$
Result	***Reject***	***Do Not Reject***	***Reject***	***Do Not Reject***	***Do Not Reject***
	Estimated Parameters				
Wilks Method	**b$_1$ (X$_{16}$)**	**b$_2$ (X$_{29}$)**	**b$_3$ (X$_{21}$)**	**b$_4$ (X$_{23}$)**	**b$_5$ (X$_{44}$)**
Hypothesis	$H_0)\ \beta_1 = 0$	$H_0)\ \beta_2 = 0$	$H_0)\ \beta_3 = 0$	$H_0)\ \beta_4 = 0$	$H_0)\ \beta_5 = 0$
Statistic Computed Value	$\chi^2 = 9.7588$	$\chi^2 = 0.3969$	$\chi^2 = 4.4051$	$\chi^2 = 4.2093$	$\chi^2 = 6.6551$
Critical Value	$\chi^2_{1;0.9} = 2.7055$	$\chi^2_{1;0.9} = 2.7055$	$\chi^2_{1;0.9} = 2.7055$	$\chi^2_{1;0.9} = 2.7055$	$\chi^2_{1;0.9} = 2.7055$
Rejection Condition	$\chi^2 \geq \chi^2_{1;0.9}$	$\chi^2 \geq \chi^2_{1;0.9}$	$\chi^2 \geq \chi^2_{1;0.9}$	$\chi^2 \geq \chi^2_{1;0.9}$	$\chi^2 \geq \chi^2_{1;0.9}$
Result	***Reject***	***Do Not Reject***	***Reject***	***Reject***	***Reject***

these probabilities are quite low, we concluded that there is not enough statistical evidence to think that the estimated parameters of the variables X_{23} and X_{44} are null. Finally, we need to consider the estimated parameter associated with the variable X_{29} – ROA. In this case, the hypothesis H_0) $\beta_2 = 0$ is not being rejected in the Wald validation method nor in the Wilks method. In fact, the maximum probability of rejecting this hypothesis when it is actually true is $\alpha_2 = 0.308$ according to the Wald's statistic and $\alpha_2 = 0.5287$ according to the Wilks' statistic. These results indicate that there is enough statistical evidence to believe that the corresponding variable should not be included in the regression model given that it does not help to identify those firms with financial problems. To verify this statement we compared the regression model that includes the variable X_{29} – ROA against that model that does not include this ratio based on the coefficients of determination and the ability of each model to identify a firm with financial problems[1]. The results obtained —as shown in **Tables 7** and **8**— indicate that the additional information provided by the variable X_{29} – ROA is negligible, and therefore, we have decided not to include this variable in the regression model.

To finalize with the validation process, we can analyze the results obtained in **Tables 7** and **8**. The most important thing to notice is the improvement that the model based on the original variables shows in comparison to the model based on the principal components. If we have a look at the coefficients of determination then the maximum value obtained for the model based on the original variables is 0.654 while for the model based on the principal components is 0.3187. In a similar way, the model based on the original variables managed to correctly identify 84.88% of the firms —either as a firm with or without financial problems— while the principal components model correctly identified 78.57% of the firms in the sample. All in all, these validation metrics reflect the robustness of the regression model selected.

Given that from the model validation we concluded that the variable X_{29} – ROA should not be considered, the new regression model can be represented as follows:

$$\hat{Y} = \frac{1}{1 + e^{-(-2.4567 + 2.2813 X_{16} + 14.2315 X_{21} - 3.563 X_{23} - 0.271 X_{44})}} \tag{5}$$

where the parameters corresponding to each financial ratio were again estimated through the maximum likelihood method. As in the previous model, the relation between the estimated parameters and the variables considered is coherent as we can see from expression (5).

The validation of this new model is quite straight forward since we only left out one financial ratio in comparison to the previous model. As in previous validations, first we tested the hypothesis H_0) *the model fits the data* and we found that there was not enough statistical evidence to reject it. Second, we tested the hypothesis H_0) $\beta_1 = \beta_2 = \cdots = \beta_k = 0$ and in this case we found out that there was enough statistical evidence to state that not all the estimated parameters are null. To continue with the validation process we also performed the significance tests of the regression coefficients. The results obtained are shown in **Table 9**. In this case, we can see that

Table 7. Comparison of the coefficients of determination.

Regression Model based on X16, X29, X21, X23, and X4		*Regression Model based on X16, X21, X23, and X44*	
Coefficients of Determination	***Value***	***Coefficients of Determination***	***Value***
R^2	0.5858	R^2	0.5504
$R^2_{McFadden}$	0.4898	$R^2_{McFadden}$	0.4865
$R^2_{Aldrich-Nelson}$	0.4044	$R^2_{Aldrich-Nelson}$	0.4028
$R^2_{Cox-Snell}$	0.4929	$R^2_{Cox-Snell}$	0.4905
$R^2_{Nagel\ker ke}$	0.6572	$R^2_{Nagel\ker ke}$	0.6540

Table 8. Comparison of the ability of the models to identify a firm with financial problems.

Regression Model based on X16, X29, X21, X23, and X44				*Regression Model based on X16, X21, X23, and X44*			
	Correct Classifications	***Incorrect Classifications***	***Total***		***Correct Classifications***	***Incorrect Classifications***	***Total***
Group 1	97.67%	2.33%	100%	*Group* 1	95.35%	4.65%	100%
Group 2	76.74%	23.26%	100%	*Group* 2	74.42%	25.58%	100%
Total	**87.21%**	**12.79%**	**100%**	***Total***	**84.88%**	**15.12%**	**100%**

Table 9. Validation results for the significance tests of the estimated parameters.

	Estimated Parameters			
Wald Method	**b_1 (X_{16})**	**b_3 (X_{21})**	**b_4 (X_{23})**	**b_5 (X_{44})**
Hypothesis	$H_0)\ \beta_1 = 0$	$H_0)\ \beta_3 = 0$	$H_0)\ \beta_4 = 0$	$H_0)\ \beta_5 = 0$
Statistic Computed Value	$t = 2.3395$	$t = 2.1002$	$t = -1.6862$	$t = -1.7514$
Critical Value	$t_{81;0.95} = 1.6639$	$t_{81;0.95} = 1.6639$	$t_{81;0.95} = 1.6639$	$t_{81;0.95} = 1.6639$
Rejection Condition	$t \ge t_{81;0.95}$	$t \ge t_{81;0.95}$	$t \le -t_{81;0.95}$	$t \le -t_{81;0.95}$
Result	***Reject***	***Reject***	***Reject***	***Reject***
	Estimated Parameters			
Wilks Method	**b_1 (X_{16})**	**b_3 (X_{21})**	**b_4 (X_{23})**	**b_5 (X_{44})**
Hypothesis	$H_0)\ \beta_1 = 0$	$H_0)\ \beta_3 = 0$	$H_0)\ \beta_4 = 0$	$H_0)\ \beta_5 = 0$
Statistic Computed Value	$\chi^2 = 9.8813$	$\chi^2 = 6.4451$	$\chi^2 = 6.4641$	$\chi^2 = 15.2369$
Critical Value	$\chi^2_{1;0.9} = 2.7055$	$\chi^2_{1;0.9} = 2.7055$	$\chi^2_{1;0.9} = 2.7055$	$\chi^2_{1;0.9} = 2.7055$
Rejection Condition	$\chi^2 \ge \chi^2_{1;0.9}$	$\chi^2 \ge \chi^2_{1;0.9}$	$\chi^2 \ge \chi^2_{1;0.9}$	$\chi^2 \ge \chi^2_{1;0.9}$
Result	***Reject***	***Reject***	***Reject***	***Reject***

every hypothesis tested $H_0)\ \beta_i = 0$ is rejected through both the Wald and Wilks methods, being the validation results more robust that in the previous regression model validation.

The validation concludes with the calculation of the coefficients of determination and the ability of the model to correctly classify the firms in the sample, which were already presented in **Tables 7** and **8**, respectively. In this way, we can finish with the regression analysis by computing the 95% confidence intervals for each of the estimated parameters from the selected regression model. The results obtained are the following:

$$\beta_1 = 2.2813 \pm 1.9407 \quad (6)$$

$$\beta_3 = 14.2315 \pm 13.4856 \quad (7)$$

$$\beta_4 = -3.563 \pm 4.2052 \quad (8)$$

$$\beta_5 = -0.271 \pm 0.308 \quad (9)$$

To summarize, we have found a logistic regression model based on a reduced group of financial ratios that is defined by expression (5). The validation results indicate that this model can better explain the total variance of the firms in the sample and that it has a higher ability to identify those firms with financial problems in comparison to that model based on the principal components. In this way, we confirm that in this particular study a big amount of information is lost if we use the principal components to develop a logistic regression model. Nevertheless, we should keep in mind that the principal component analysis has resulted very useful to represent and quickly asses the financial status of a firm based on the risk the company has with regard to the nature of its business and the risk involved in the amount of debt it has taken in comparison to the profits that were generated during the last two fiscal years. In fact, both the principal component and the regression analyses have resulted in two complementary tools that allow us to evaluate and summarize the financial status of a firm based on the data from its balance sheets.

6. Applying the Analyses to a New Sample

The objective of this section is to evaluate the effectiveness that the principal component and the regression analyses have to identify those firms with financial problems when they are applied over a new sample.

Given to the difficulties involved in the data collection, the new sample is composed by 14 companies from which only 3 of them have had financial problems (see Appendix 8 for the sample details). Moreover, we should notice that the data collected from these firms corresponds to periods previous than 2002, which means that there might be some unusual variation in the data due to the financial crisis that occurred in Argentina between 2001 and 2002. Nevertheless, despite of these data limitations the evaluation performed is still valid although the results will have to be carefully interpreted.

To start with, the values of the principal components $F_1 - \Delta Risk$ and $F_2 - \Delta Return$ have been computed for each firm and are represented in **Figure 6**. From this figure we can see that the 3 companies that have had financial problems are located within sector 2, which corresponds to a high risk level together with a return deterioration. At the same time, most of the companies that did not have financial problems are also located in the same sector with the exception of 2 firms that are located in sector 6, which corresponds to a high level of risk together with a return improvement. In this way, if we would have to classify the firms from the new sample based uniquely on the principal components analysis we would say that all those firms within sector 2 have a higher probability of becoming financially distressed in the short term while the opposite occurs with those companies from sector 6. The higher probability of having financial problems for those companies in sector 2 is mainly derived from the higher risk they have due to the nature of the business —as determined by the operating leverage— and the higher risk they are taking when increasing their debts without generating enough resources to cover it. Nevertheless, in order to obtain a more precise classification we should performed the regression analysis as shown next.

To finalize with the evaluation of the effectiveness of the tools developed, we performed the logistic regression analysis over the new sample and we computed for each firm the probabilities of becoming financially distressed in the short term as shown in **Table 10**. Based on these results and keeping in mind that those firms with a probability equal or higher than 0.5 are considered to have financial problems, we can conclude that all companies were correctly classified within one of the two groups considered. This suggests that the tools developed are useful and effective to identify those firms with financial problems. Of course, we can always expect some classification error but in this case it seems not to be significant.

It is important to mention how the two analyses performed complement each other. From the principal component analysis we can quickly identify those companies that are taking a higher risk —based on the nature

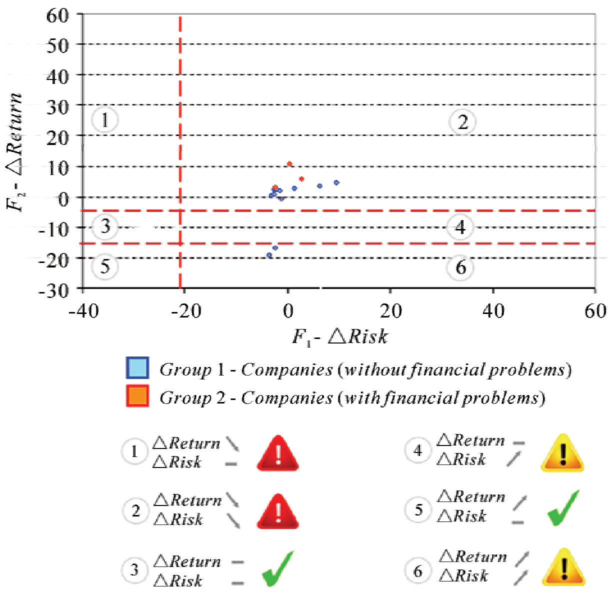

Figure 6. Categorization of the firms from the new sample based on the principal components.

Table 10. Probabilities for a firm to become financially distressed in the short term.

Firm Nr	*Group Nr*	*Probability*
1	1	0.0045
2	1	0.2164
3	1	0.1569
4	1	0.3691
5	1	0.2479
6	1	0.0863
7	1	0.2680
8	1	0.4766
9	1	0.1244
10	1	0.3013
11	1	0.2462
12	2	0.5593
13	2	0.7444
14	2	0.5279

of the business and based on the higher debts— and to identify those companies that have a better coverage against that risk. From the regression analysis we are able to quantify through a unique indicator —the probability of becoming financially distressed in the short term— how big is the risk involved and how good is the company covering against that risk. In addition, we can use this probability to identify those firms that already have financial problems.

7. Conclusions

Through this study we managed to verify based on the statistical analyses performed that the financial ratios show a different behavior between those firms that have had financial problems and those which did not. Although not all these ratios have by themselves the same ability to allow the identification of those firms with financial problems, it is possible to combine and summarize all that information into 2 principal components that we have named as Δ*Risk* and Δ*Return*. By the computation of these new variables it is possible to quickly financially categorize a certain firm based on the risk the company has with regard to the nature of its business and the risk involved in the amount of debt it has taken in comparison to the profits that were generated during the last two fiscal years.

The conclusive results obtained from the principal component analysis suggest that there would be no apparent reason not to consider any financial ratio originally collected to estimate the probability that a firm becomes financially distressed in the short term. However, after developing different regression models we have seen that we can obtain better estimations of these probabilities if we just consider a few financial ratios that all together show a higher ability to identify a firm with financial problems in comparison to a situation where the data collected from all the 45 ratios is used (as in the case of the principal components model). In this way, we managed to develop a more efficient model given that we can obtain better results with less data. This efficiency can be explained due to the fact that the principal components are a linear combination of 45 ratios, which means that many of them might not be useful to distinguish between a financially healthy firm and one that it is not. This finding shows how important is to have a complete and broad database before starting any statistical analysis so that fewer limitations are introduced when trying to find a near optimal solution, *i.e.* the regression model with the available ratios combination that best estimates the probability of a firm of becoming financially distressed in the short term. In the same way, we should emphasis the benefits that can be obtained when combining more than one statistical analysis together to better understand the nature of the process under study and to more effectively achieve the objective proposed, which in our case is to identify those firms with financial problems.

We have seen that those ratios that have more capabilities to identify those firms with financial problems are all related to the return aspects of the companies. In fact, we have seen that the principal component that resulted more conclusive to identify financially unhealthy firms was the Δ*Return* as opposite to the Δ*Risk* component. Nevertheless, the information contained in these ratios can always be complemented with information from other type of ratios to identify those firms with financial problems more precisely and effectively. After performing a logistic regression analysis based on the 45 ratios collected in the sample, we have selected a small group of them that can explain 65% of the firms' behavior. The related model consists of the following ratios: 1) *Current Debt Ratio*, 2) *Total Cost of Debt*, 3) *Operating Profit Margin*, and 4) Δ*ROE*. It is interesting to notice that in most of the logistic regression models tested it was found that there is higher probability to incorrectly classify a firm with financial problems, *i.e.* to assume that a company is financially healthy when actually it is not. This could be mainly explained due to the fact that the financial ratios collected have a higher variability in those companies that are financially distressed in comparison to those that do not have any financial problem. Nevertheless, the possibility of combining the regression and the principal component analyses helps to reduce the probability of misclassifying a certain firm. With this regard, we should notice that the present study does not include any analysis related to the costs involved in the decision making process of identifying firms with financial problems. Nevertheless, whenever there are not conclusive results that clear define the financial status of a company then the most conservative decision would be to assume that the firm has financial problems.

The outcomes from this study are two tools that were developed based on the statistical inference from which we can quickly asses the financial status of a firm based on its risks and return's variation as well as to estimate the probability that a firm becomes financially distressed in the short term. There are different ways of taking these tools into practice such as: 1) to control and follow up the financial performance of a company, 2) to support the decision of lending money to a company, 3) to support the decision of investing money or the decision of merging with a company, 4) to support market analysis from a financial perspective, and 5) to support actions or decisions related to the financial assessment of a company that declares itself to be financially distressed.

This study could be further developed by trying to incorporate new explanatory variables that are rather not financial ratios but instead qualitative measurements that could contribute to more precise and effective estimation of the probability of a firm of becoming financially distressed in the short term. Another alternative would be to incorporate a tool from which the costs involved in taking the wrong decision —*i.e.* to assume that a company has no financial problems when it actually has or vice versa— could be minimized. Finally, the statistical analyses performed in this study could be replicated with firms that have a significant amount of assets with the objective of determining the main characteristics that derive in a solid financial structure. As we can see, there are many different ways to continue with this study and the statistics offers interesting tools for that.

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Appendices

Appendix 1

Table A1. Details of the firms included in the sample.

Firm Nr	*Group Nr*	*Name*	*Period Analyzed*	*Firm's Industry*
1	1	*Alvarez Hnos. S.A.*	2005-2004	*Mills and oils*
2	1	*Compañía Internacional de Alimentos y Bebidas S.A.*	2004-2003	*Food*
3	1	*Establecimiento Metalúrgicos Cavanna S.A.C.I.F.I.*	2005-2004	*Technology and communications*
4	1	*Andreani Logística S.A.*	2004-2003	*Transport*
5	1	*Compañía de Servicios Telefónicos S.A.*	2005-2004	*Telecommunications*
6	1	*Compumundo S.A.*	2005-2004	*Retail*
7	1	*Caputo S.A.*	2005-2004	*Construction*
8	1	*Ediar S.A.*	2005-2004	*Printing and publishing*
9	1	*Agrometal S.A.I.*	2005-2004	*Machinery and equipment*
10	1	*Electromac S.A.*	2005-2004	*Machinery and equipment*
11	1	*Gijon S.A.*	2005-2004	*Construction*
12	1	*Green S.A.*	2005-2004	*Construction*
13	1	*Esat S.A.*	2004-2003	*Plastic and chemical*
14	1	*Grafex S.A.*	2004-2003	*Printing and publishing*
15	1	*Lihue Ingeniería S.A.*	2005-2004	*Machinery and equipment*
16	1	*Laboratorio LKM S.A.*	2004-2003	*Laboratories*
17	1	*Guilford Argentina S.A.*	2005-2004	*Textiles and footwear*
18	1	*Rovella Carranza S.A.*	2005-2004	*Construction*
19	1	*Yar Construcciones S.A.*	2005-2004	*Construction*
20	1	*Mardi S.A.*	2004-2003	*Fishing*
21	1	*Mercoplast S.A.*	2005-2004	*Plastic and chemical*
22	1	*Bonafide Golosinas S.A.*	2005-2004	*Food*
23	1	*Bonesi S.A.*	2005-2004	*Household goods*
24	1	*Molinos Juan Semino S.A.*	2004-2003	*Mills and oils*
25	1	*City Pharma S.A.*	2005-2004	*Retail*
26	1	*Morixe Hnos. S.A.*	2005-2004	*Mills and oils*
27	1	*Coniglio S.A.*	2005-2004	*Textiles and footwear*
28	1	*Curtiduría A. Gaita S.R.L.*	2005-2004	*Tanneries and leather goods*
29	1	*Domec S.A.I.C. y F.*	2005-2004	*Household goods*
30	1	*Dulcor S.A.*	2005-2004	*Food*
31	1	*Distribuidora Santa Bárbara S.A.*	2005-2004	*Fishing*
32	1	*Outdoors S.A.*	2004-2003	*Textiles and footwear*
33	1	*Frutucumán S.A.*	2003-2002	*Export and import*
34	1	*García Reguera S.A.*	2005-2004	*Wholesale*
35	1	*Instituto Rosenbusch S.A.*	2005-2004	*Healthcare*
36	1	*Insumos Agroquímicos S.A.*	2005-2004	*Retail*
37	1	*Industria Textil Argentina (INTA) S.A.*	2005-2004	*Textiles and footwear*
38	1	*SAT Médica S.A.*	2005-2004	*Healthcare*
39	1	*Leyden S.A.I.C. y F.*	2005-2004	*Machinery and equipment*
40	1	*Lodge S.A.*	2004-2003	*Agricultural*

41	1	*Longvie S.A.*	2005-2004	*Household goods*
42	1	*Ovoprot International S.A.*	2004-2003	*Food*
43	1	*Magalcuer S.A.*	2005-2004	*Tanneries and leather goods*
44	2	*Aero Vip S.A.*	2003-2002	*Transport*
45	2	*Alunamar S.A.*	2005-2004	*Fishing*
46	2	*American Falcon S.A.*	2003-2002	*Transport*
47	2	*AS Sistemas S.A.*	2003-2002	*Technology and communications*
48	2	*Bascoy S.A.*	2003-2002	*Transport*
49	2	*Cartex S.A.*	2004-2003	*Textiles and footwear*
50	2	*Casamen S.A.*	2003-2002	*Food*
51	2	*Celeritas S.A.*	2004-2003	*Healthcare*
52	2	*Comercial Mendoza S.A.*	2003-2002	*Household goods*
53	2	*Crédito José C. Paz S.A.*	2003-2002	*Construction*
54	2	*D´Vigi S.A.*	2004-2003	*Retail*
55	2	*Droguería Sigma S.A.*	2003-2002	*Retail*
56	2	*Ecourban S.A.*	2004-2003	*Waste*
57	2	*El Manzanar de Macedo S.A.*	2004-2003	*Food*
58	2	*Espejos Versailles S.A.*	2003-2002	*Glass and construction materials*
59	2	*FrigoFruit S.A.*	2003-2002	*Agricultural*
60	2	*Humberto Nicolás Fontana S.A.C.*	2004-2003	*Household goods*
61	2	*Impresiones Arco Iris Córdoba S.A.*	2003-2002	*Printing and publishing*
62	2	*Industrias Badar S.A.*	2003-2002	*Technology and communications*
63	2	*Diabolo Menthe S.R.L.*	2003-2002	*Textiles and footwear*
64	2	*La Tribu S.R.L.*	2003-2002	*Food*
65	2	*Loucen International S.A.*	2004-2003	*Beverages*
66	2	*Luicar S.R.L.*	2003-2002	*Turism*
67	2	*Manfisa Mandataria y Financiera S.A.*	2003-2002	*Construction*
68	2	*Norte Asistencia Empresaria S.A.*	2003-2002	*Post*
69	2	*Parmalat Argentina S.A.*	2003-2002	*Dairy*
70	2	*Pto. S.A.*	2004-2003	*Waste*
71	2	*Redes Excon S.A.*	2003-2002	*Gas*
72	2	*Sanatorio Ezeiza S.A.*	2004-2003	*Healthcare*
73	2	*Sanatorio Modelo Quilmes S.A.*	2004-2003	*Healthcare*
74	2	*Security Consulting S.A.*	2003-2002	*Technology and communications*
75	2	*Sepia Beauty S.A.*	2004-2003	*Cleaning and cosmetics*
76	2	*Sol de Brasa S.A.*	2005-2004	*Agricultural*
77	2	*Sycon Argentina S.A.*	2003-2002	*Gas*
78	2	*UOL Sinectis S.A.*	2004-2003	*Technology and communications*
79	2	*Yearling S.A.*	2003-2002	*Security services*
80	2	*Fundición de Aceros S.A.*	2003-2002	*Metallurgical and steel*
81	2	*Inmar S.A.*	2003-2002	*Construction*
82	2	*Carpintería Metálica San Eduardo S.A.*	2003-2002	*Glass and construction materials*
83	2	*Marmolería Sierra Chica S.A.*	2003-2002	*Mining*
84	2	*Avaca S.A.*	2003-2002	*Textiles and footwear*
85	2	*Bellas S.A.*	2003-2002	*Textiles and footwear*
86	2	*Ianson S.A.*	2004-2003	*Textiles and footwear*

Appendix 2

Table A2. Description of the financial ratios included in the analyses.

Liquidity Ratios		
X_1.	*Fixed Assets Ratio*	Non Current Assets / Total Assets
X_2.	*Working Capital Ratio*	Working Capital / Total Assets
X_3.	*Current Ratio*	Current Assets / Current Liabilities
X_4.	*Quick Ratio*	(Current Assets - Inventory) / Current Liabilities
X_5.	*Cash Ratio*	Cash & Equivalents / Current Liabilities
X_6.	*Average Receivables Collection Period*	Receivables / Sales
X_7.	*Payables Payment Period*	Accounts Payable / Purchases
X_8.	*Average Inventory Processing Period*	Average Inventory / COGS
X_9.	*Cash Conversion Cycle*	Avg. Inventory Processing Period + Avg. Receivables Collection Period - Avg. Payables Payment Period
Operating Efficiency Ratios		
X_{10}.	*Total Asset Turnover*	Sales / Total Assets
X_{11}.	*Current Assets Turnover*	Sales / Current Assets
X_{12}.	*Fixed Asset Turnover*	Sales / Non Current Assets
X_{13}.	*Equity Turnover*	Equity / Sales
Business Risk Ratios		
X_{14}.	*Operating Leverage*	$\mid$ (%ΔOperating Income) / (%ΔSales) $\mid$
Financial Risk Ratios		
X_{15}.	*Total Debt Ratio*	Total Liabilities / Total Assets
X_{16}.	*Current Debt Ratio*	Current Liabilities / Total Assets
X_{17}.	*Debt Turnover*	Total Liabilities / Sales
X_{18}.	*Non Current Debt Ratio*	Non Current Liabilities / (Non Current Liabilities + Equity)
X_{19}.	*Equity To Debt Ratio*	Equity / Total Liabilities
X_{20}.	*Debt Coverage*	Operating Profit / Total Liabilities
X_{21}.	*Total Cost of Debt*	Interests / Total Liabilities
Return Ratios		
X_{22}.	*Gross Profit Margin*	Gross Profit / Sales
X_{23}.	*Operating Profit Margin*	Operating Profit / Sales
X_{24}.	*Net Profit Margin*	Net Income / Sales
X_{25}.	*Return on Equity (ROE)*	Net Income / Equity
X_{26}.	*Benchmarked Return*	(ROE - *ROE sector*) / *ROE sector*
X_{27}.	*Return on Capital Employed (ROCE)*	Net Income / (Total Liabilities + Equity)
X_{28}.	*Operating Return on Capital Employed*	Operating Profit / (Total Liabilities + Equity)
X_{29}.	*Return on Assets (ROA)*	Net Income / Total Assets
X_{30}.	*Operating Profit on Assets*	Operating Profit / Total Assets
Growth Ratios		
X_{31}.	*ΔSales*	(Sales j - Sales j-1) / Sales j-1

X_{32}.	*ΔAssets*	(Total Assets j - Total Assets j-1) / Total Assets j-1
X_{33}.	*ΔNet Income*	(Net Income j - Net Income j-1) / Net Income j-1
X_{34}.	*ΔLiabilities*	(Total Liabilities j - Total Liabilities j-1) / Total Liabilities j-1
X_{35}.	*ΔFixed Assets Ratio*	(Fixed Asset Ratio j - Fixed Asset Ratio j-1) / Fixed Asset Ratio j-1
X_{36}.	*ΔWorking Capital*	(Working Capital j - Working Capital j-1) / Working Capital j-1
X_{37}.	*ΔCurrent Ratio*	(Current Ratio j - Current Ratio j-1) / Current Ratio j-1
X_{38}.	*ΔAssets Turnover*	(Assets Turnover j - Assets Turnover j-1) / Assets Turnover j-1
X_{39}.	*ΔTotal Debt Ratio*	(Total Debt Ratio j - Total Debt Ratio j-1) / Total Debt Ratio j-1
X_{40}.	*ΔDebt Turnover*	(Debt Turnover j - Debt Turnover j-1) / Debt Turnover j-1
X_{41}.	*ΔDebt Coverage*	(Debt Coverage j - Debt Coverage j-1) / Debt Coverage j-1
X_{42}.	*ΔOperating Profit Margin*	(Operating Profit Margin j - Operating Profit Margin j-1) / Operating Profit Margin j-1
X_{43}.	*ΔNet Profit Margin*	(Net Profit Margin j - Net Profit Margin j-1) / Net Profit Margin j-1
X_{44}.	*ΔROE*	(ROE j - ROE j-1) / ROE j-1
X_{45}.	*ΔROA*	(ROA j - ROA j-1) / ROA j-1

Appendix 3

In **Table A3** we present the average ROE per industry based on data published on [12-14]. These average returns have been used to compute the *Benchmarked Return* ratio for each company in the sample.

Table A3. Average ROE per industry for companies operating in Argentina.

	Year		
Firm's Industry	**2003**	**2004**	**2005**
Agricultural	26.81	29.23	27.02
Household goods	68.18	29.17	39.83
Automotive	31.09	28.27	29.64
Beverages	33.51	34.01	29.01
Pulp and paper	34.75	17.28	18.87 (*)
Wholesale	38.81	36.43	33.44
Retail	51.69	32.95	67.25
Road concessionaire	86.56 (*)	95.16	103.89 (*)
Construction	94.78	47.44	649.63
Post	44.75	48.79 (*)	53.27 (*)
Tanneries and leather goods	42.31	52.54	73.68
Gas	33.24	37.66	28.04
Export and import	43.65 (*)	47.99	52.39 (*)
Finance	257.69	64.35	53.62
Meat	115.63	40.12	43.80 (*)
Oil and gas	128.53	28.81	46.18
Turism	3.24	3.53 (*)	3.86 (*)
Printing and publishing	450.50	33.94	23.91
Fishing	31.19 (*)	34.29	37.43 (*)
Lanoratories	79.01	55.35	60.43
Dairy	39.20 (*)	43.10	87.80
Cleaning and cosmetics	158.33	172.63 (*)	188.48 (*)
Machinery and equipment	124.00	48.32	40.18
Metallurgical and steel	58.72	30.03	31.82
Mining	162.68	22.22	45.05
Mills and oils	74.89	24.18	47.77
Rubber products	28.59	31.17 (*)	28.42
Other	32.61 (*)	35.85 (*)	39.47
Production and distribution of electrical energy	46.30	18.01	56.93
Food	35.35	42.88	38.85
Film Products	14.98 (*)	16.47	17.98 (*)
Plastic and chemical	65.97	18.64	77.78
Chemical and petrochemical	62.35	36.03	36.26

Waste	6.90 (*)	7.57 (*)	8.32
Healthcare	27.69 (*)	30.43	33.23 (*)
Security services	41.31 (*)	45.41 (*)	50.00
Tobacco	23.69 (*)	26.04 (*)	28.67
Technology and communications	61.96 (*)	68.12 (*)	75.00
Telecommunications	58.82	363.10	57.18
Textiles and footwear	15.16 (*)	16.67	18.20 (*)
Transport	60.13	163.61	100.65
Glass and construction materials	1100.00	22.19	29.56

(*) These returns are estimations based on the return of that sector from other years adjusted by the corresponding ΔGDP.

Appendix 4

In **Table A4** we present the eigenvalues for each principal component obtained through the covariance matrix. We can see from these results that the first two components already accumulate approximately 93% of the total sample variance.

Table A4. Eigenvalues for the principal components.

	Eigenvalues	*Cumulative Variance*		*Eigenvalues*	*Cumulative Variance*
F_1	**17862.89**	**84.69%**	F_{23}	0.33	99.99%
F_2	**1792.07**	**93.19%**	F_{24}	0.29	100.00%
F_3	576.15	95.92%	F_{25}	0.21	100.00%
F_4	455.55	98.08%	F_{26}	0.18	100.00%
F_5	134.53	98.72%	F_{27}	0.15	100.00%
F_6	88.47	99.14%	F_{28}	0.11	100.00%
F_7	62.48	99.44%	F_{29}	0.09	100.00%
F_8	50.57	99.68%	F_{30}	0.06	100.00%
F_9	19.58	99.77%	F_{31}	0.06	100.00%
F_{10}	11.70	99.82%	F_{32}	0.04	100.00%
F_{11}	9.40	99.87%	F_{33}	0.03	100.00%
F_{12}	5.51	99.89%	F_{34}	0.02	100.00%
F_{13}	4.74	99.92%	F_{35}	0.02	100.00%
F_{14}	4.25	99.94%	F_{36}	0.01	100.00%
F_{15}	3.89	99.96%	F_{37}	0.01	100.00%
F_{16}	2.13	99.97%	F_{38}	0.01	100.00%
F_{17}	1.94	99.97%	F_{39}	0.01	100.00%
F_{18}	1.11	99.98%	F_{40}	0.00	100.00%
F_{19}	0.95	99.98%	F_{41}	0.00	100.00%
F_{20}	0.71	99.99%	F_{42}	0.00	100.00%
F_{21}	0.50	99.99%	F_{43}	0.00	100.00%
F_{22}	0.39	99.99%	F_{44}	0.00	100.00%
			F_{45}	0.00	100.00%

Appendix 5

In **Table A5** we present the values that the two principal components selected have in each firm from the sample. Based on these values, it is possible to represent the firms in a unique graph as shown in Section 4.

Table A5. Values of the principal components for each firm included in the sample.

Firm Nr	F_1	F_2	*Firm Nr*	F_1	F_2
1	2.89	−8.73	44	−21.32	−11.43
2	−7.46	−13.63	45	−24.91	−10.17
3	−29.61	−9.03	46	−29.61	−8.20
4	−28.65	−9.93	47	−27.52	−12.12
5	−25.48	−11.18	48	−27.59	−8.34
6	−28.02	−9.82	49	−19.58	56.95
7	−24.38	−11.21	50	−27.25	−2.63
8	−29.96	−23.40	51	−10.80	348.78
9	−25.94	−9.77	52	−28.00	77.40
10	6.56	−29.62	53	83.18	−0.38
11	−27.35	−12.27	54	22.53	28.75
12	−13.12	−8.80	55	−24.40	−7.53
13	−26.62	−10.99	56	−19.52	−4.45
14	−27.68	−12.63	57	−16.61	−0.07
15	−21.24	−10.02	58	−27.95	−8.51
16	−9.81	−6.73	59	−29.01	−10.73
17	−29.29	−9.85	60	−29.00	−8.98
18	−28.17	−17.67	61	−18.88	−11.57
19	−29.11	−21.38	62	1,168.66	−28.96
20	21.88	−6.99	63	143.16	65.74
21	−27.91	−9.38	64	−9.03	5.18
22	−23.66	−11.65	65	−23.78	−24.24
23	−29.71	−10.96	66	−29.17	−8.94
24	−28.14	−11.62	67	−18.11	−2.91
25	−29.48	−9.49	68	−28.57	−11.15
26	44.80	16.75	69	−28.76	65.83
27	−26.62	−11.21	70	−25.86	−13.43
28	20.48	−6.61	71	−29.66	−7.74
29	−26.89	−11.24	72	−29.15	−9.30
30	−16.64	−8.22	73	−23.67	−8.33
31	−26.94	−10.14	74	−30.66	−3.28
32	−28.95	−10.66	75	−14.80	−5.93
33	49.83	0.62	76	−26.39	6.42
34	−18.95	−21.99	77	−28.18	17.90
35	−28.73	−10.61	78	−26.25	−8.48
36	−28.63	−9.81	79	−29.34	−2.67
37	−29.95	−9.09	80	−27.60	−7.34
38	−27.47	−11.72	81	−29.40	−7.81
39	−25.99	−10.93	82	296.70	55.26
40	−18.58	−7.64	83	−29.29	−10.68
41	−22.00	−14.59	84	0.38	−7.52
42	−28.22	−11.83	85	−29.25	5.02
43	−29.07	−8.22	86	−27.74	4.48

Appendix 6

In **Table A6** we present the correlation between the two principal components selected and each of the financial ratios included in this study. We have highlighted those ratios that have a higher correlation with one of the principal components.

Table A6. Correlation between the principal components selected and the financial ratios included in the analyses.

Variable	F_1	F_2
X_1	−0.0450	0.0003
X_2	0.0092	−0.1531
X_3	−0.0218	0.0707
X_4	−0.0395	0.0364
X_5	−0.0744	−0.0786
X_6	−0.0150	−0.0299
X_7	−0.0251	−0.0285
X_8	0.0005	0.0194
X_9	0.0031	−0.0038
X_{10}	−0.0297	0.1808
X_{11}	−0.0395	0.1606
X_{12}	−0.0299	−0.0295
X_{13}	−0.0203	−0.0365
$\mathbf{X_{14}}$	**0.9984**	0.0221
X_{15}	−0.0457	0.1748
X_{16}	−0.0357	0.1921
X_{17}	−0.0323	−0.0277
X_{18}	−0.0480	−0.0363
X_{19}	−0.0285	−0.2219
X_{20}	−0.0700	−0.3777
X_{21}	0.2276	0.0313
X_{22}	−0.0650	−0.0932
X_{23}	−0.0032	−0.1069
X_{24}	−0.0039	−0.0835
X_{25}	0.0158	−0.1549
X_{26}	0.0056	−0.1566
X_{27}	0.0149	−0.1681
X_{28}	−0.0453	−0.1014
X_{29}	−0.0167	−0.4457
X_{30}	−0.0304	−0.3643
X_{31}	−0.0262	0.0885
X_{32}	−0.0842	−0.0678
$\mathbf{X_{33}}$	−0.0033	**−0.9688**
X_{34}	−0.0819	0.2591
X_{35}	−0.0251	0.1044
X_{36}	−0.0677	−0.0351
X_{37}	−0.0223	0.1054
X_{38}	0.0124	0.2825
$\mathbf{X_{39}}$	−0.0323	**0.5329**
X_{40}	−0.0752	−0.0004
$\mathbf{X_{41}}$	**0.8628**	−0.2082
$\mathbf{X_{42}}$	**0.8120**	−0.2345
$\mathbf{X_{43}}$	−0.0141	**−0.7122**
X_{44}	−0.0294	−0.4114
$\mathbf{X_{45}}$	−0.0143	**−0.9859**

Appendix 7

In **Table A7** we present the 57 logistic regression models that were tested based on the standard and the Nagelkerke regression coefficients.

Table A7. Ranking of the logistic regression models based on the regression coefficients.

Model Nr	*Variables Considered*					R^2	$R^2_{Nagel\ ker\ ke}$
1	X_{16}	X_{19}	X_{21}	X_8	X_{44}	0.57	0.67
2	$\mathbf{X_{16}}$	$\mathbf{X_{29}}$	$\mathbf{X_{21}}$	$\mathbf{X_{23}}$	$\mathbf{X_{44}}$	**0.58**	**0.66**
3	X_{16}	X_{29}	X_5	X_{21}	X_{44}	0.55	0.65
4	X_{16}	X_{29}	X_5	X_{21}	X_{23}	0.56	0.65
5	X_{16}	X_{29}	X_{26}	X_{23}	X_{44}	0.55	0.65
6	X_{16}	X_{25}	X_{29}	X_8	X_{43}	0.53	0.64
7	X_{16}	X_{25}	X_{29}	X_8	X_{21}	0.54	0.64
8	X_{16}	X_{29}	X_5	X_{23}	X_{44}	0.53	0.64
9	X_{16}	X_{29}	X_5	X_{44}	X_{17}	0.50	0.64
10	X_{16}	X_{29}	X_{26}	X_{24}	X_{44}	0.53	0.64
11	X_{16}	X_{29}	X_{21}	X_{24}	X_{44}	0.57	0.64
12	X_{16}	X_{29}	X_5	X_{21}	X_{17}	0.52	0.63
13	X_{16}	X_{19}	X_{21}	X_2	X_{44}	0.54	0.63
14	X_{16}	X_{25}	X_8	X_{29}	X_{19}	0.52	0.62
15	X_{16}	X_{29}	X_5	X_{21}	X_{43}	0.52	0.62
16	X_{16}	X_{29}	X_5	X_{44}	X_{42}	0.50	0.62
17	X_{16}	X_{29}	X_{21}	X_{44}	-	0.54	0.62
18	X_{16}	X_{19}	X_{21}	X_3	X_{44}	0.54	0.62
19	X_{16}	X_{25}	X_8	X_{29}	-	0.51	0.61
20	X_{16}	X_{25}	X_{29}	X_5	X_{21}	0.52	0.61
21	X_{16}	X_{29}	X_5	X_{21}	X_{33}	0.51	0.61
22	X_{16}	X_{29}	X_5	X_{21}	X_{32}	0.60	0.61
23	X_{16}	X_{29}	X_5	X_{21}	X_{45}	0.51	0.61
24	X_{16}	X_{29}	X_5	X_{21}	X_{34}	0.51	0.61
25	X_{16}	X_{29}	X_5	X_{23}	-	0.50	0.61
26	X_{16}	X_{29}	X_5	X_{44}	-	0.48	0.61
27	X_{16}	X_{29}	X_5	X_{44}	X_{20}	0.49	0.61
28	X_{16}	X_{29}	X_5	X_{44}	X_{33}	0.49	0.61
29	X_{16}	X_{29}	X_5	X_{44}	X_{11}	0.51	0.61
30	X_{16}	X_{29}	X_2	X_{21}	X_{43}	0.52	0.60
31	X_{16}	X_{29}	X_{21}	X_3	X_{25}	0.53	0.60
32	X_{16}	X_{25}	X_{29}	X_{21}	X_3	0.53	0.60
33	X_{16}	X_{25}	X_{29}	X_{21}	X_2	0.52	0.60
34	X_{16}	X_{29}	X_5	X_{21}	-	0.50	0.60
35	X_{16}	X_{29}	X_5	X_{21}	X_{42}	0.50	0.60

36	X_{16}	X_{29}	X_5	X_{21}	X_{26}	0.51	0.60
37	X_{16}	X_{29}	X_{21}	X_{23}	-	0.54	0.60
38	X_{16}	X_3	X_{25}	X_{33}	X_8	0.49	0.59
39	X_{16}	X_{25}	X_{29}	X_5	-	0.48	0.58
40	X_{16}	X_{25}	X_{29}	X_5	X_{20}	0.48	0.58
41	X_{16}	X_3	X_{25}	X_{33}	X_{29}	0.49	0.57
42	X_{15}	X_{29}	X_2	X_{43}	X_{21}	0.50	0.57
43	X_{16}	X_{29}	X_8	-	-	0.47	0.57
44	X_{16}	X_{25}	X_{29}	X_3	-	0.49	0.57
45	X_{16}	X_{25}	X_{29}	X_2	-	0.49	0.57
46	X_{16}	X_{29}	X_5	-	-	0.45	0.57
47	X_{16}	X_{25}	X_{29}	-	-	0.48	0.56
48	X_{16}	X_{29}	X_{21}	-	-	0.49	0.56
49	X_{16}	X_3	X_{25}	X_{33}	X_{19}	0.44	0.55
50	X_{16}	X_{29}	X_3	-	-	0.47	0.55
51	X_{16}	X_{25}	X_3	-	-	0.41	0.53
52	X_{45}	X_{43}	X_{33}	X_{39}	-	0.28	0.36
53	X_{45}	X_{43}	X_{39}	-	-	0.27	0.36
54	X_{14}	X_{41}	X_{42}	X_{45}	X_{33}	0.27	0.34
55	X_{45}	X_{33}	X_{43}	-	-	0.25	0.34
56	X_{45}	X_{43}	-	-	-	0.24	0.33
57	X_{14}	X_{41}	X_{42}	-	-	0.12	0.14

Appendix 8

In **Table A8** we present the companies that were included in the second sample to evaluate the performance of the principal component and the logistics regression analyses to identify those firms with financial problems.

Table A8. Details of the firms included in the new sample.

Firm Nr	*Group Nr*	*Name*	*Period Analyzed*	*Firm's Industry*
1	1	*Patricios S.A.*	2004-2003	*Plastic and chemical*
2	1	*Fiplasto S.A.*	2005-2004	*Export and import*
3	1	*Grupo Inplast S.A.*	2003-2002	*Agricultural*
4	1	*Grimoldi S.A.*	2005-2004	*Textiles and footwear*
5	1	*Limpiolux S.A.*	2005-2004	*Other*
6	1	*La Agraria S.A.*	2005-2004	*Agricultural*
7	1	*Amercian Plast S.A.*	2004-2003	*Plastic and chemical*
8	1	*Compañía argentina de semillas*	2005-2004	*Agricultural*
9	1	*Schiarre S.A.*	2004-2003	*Machinery and equipment*
10	1	*Sports Life S.A.*	2005-2004	*Retail*
11	1	*UOLE S.A.*	2005-2004	*Household goods*
12	2	*Sweet Victorian S.A.*	2001-2000	*Textiles and footwear*
13	2	*Metcasa Metalúrgica Callegari S.A.*	2001-2000	*Metallurgical and steel*
14	2	*Midan S.A.*	2000-1999	*Automotive*

J. Service Science & Management, **2010, 3, 336-344**
doi:10.4236/jssm.2010.33039 Published Online September 2010 (http://www.SciRP.org/journal/jssm)

How Do Companies Adjust their Independent Directors after a Mishap

—Evidence from Independent Directors' Background

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Received April 23rd, 2010; revised June 6th, 2010; accepted July 10th, 2010.

ABSTRACT

Selection of independent directors in China's listed companies is a two-way choice dominated by listed companies. Thereafter, most companies adjust their independent directors after a mishap (e.g. receiving qualified audit opinions or punished by regulatory authorities). This paper investigates the behavior of how companies adjust their independent directors from the perspective of independent directors' background, by using data of Chinese listed companies to which a mishap happened between 2002 *and* 2004 *as our target sample. Evidence shows that listed companies will increase independent directors with accounting background significantly after receiving qualified audit opinions or punished by regulatory authorities, for the purpose of mitigating distress from capital market and medium and minority shareholders, which highlights the supervising role of independent directors with accounting background. Besides, these companies enjoy significantly contemporaneous return after the adjustment.*

***Keywords*:** *Independent Directors, Adjust, Background, Corporate Governance*

1. Introduction

Independent director system is widely believed as an important action to improve corporate governance and now becomes the common choice among different corporate governance patterns [1]. In china, the system comprised of three parties (*i.e.* China Securities Regulatory Commission, listed companies and independent directors) was enforced as a "life saving straw" in 2001 when reform on non-tradable shares encounters a variety of difficulties. To better protect interests of medium and minority shareholders, China Securities Regulatory Commission (CSRC thereafter), one of the most important regulatory authorities in China's capital market, issued guidance on establishing independent directors system in listed companies (the Guidance thereafter) on August 16, 2001, which gave birth to China's independent directors system.

In consequence, a huge "blind date" between listed companies and independent directors carries on amid fire and thunder. In reality, listed companies have made sufficient comparison and consideration among different candidates before formal invitations and employment. A person who is assigned to be an independent director must have some strength which is favored by companies, such as social status, professional skills, networking resources or just easy to be controlled [2]. Meanwhile, independent directors can not only get paid, but also reputation, which was deem as the "fame and fortune" appointment. Therefore, selection of independent directors in Chinese listed companies is a two-way choice dominated by listed companies. What's the motivation of listed companies in the selections? Do they have adequate incentives to choose independent directors for supervising? This is the main question we are going to answer first.

However, whether the system is perfect designed need further investigation. The collapse of Enron, WorldCom, and similar but less catastrophic disclosure failures vividly demonstrated weaknesses in the board governance system produced by the 1990s and pointed the way towards new roles for independent directors and standards of independence [3]. At the end of 1997, Zhengbaiwen was operating at a loss, and so falsified its financial report to make stockholders believe that the company was doing well. This caused stockholders a 98.79% loss in

1998. Listed companies have autonomies in initial selections; however, they will be challenged by medium and minority shareholders or even punished by law when mishap happens. Besides, mass media functions as a "watch dog" on shareholders' interest in the whole process. As we all see that independent director Jiahao Lu was fined RMB 100,000 in "Zhengbaiwen Event", for failing to take action when the company submitted a false financial report. Thus, the question arises: will listed companies adjust independent directors as a means to mitigate pressures from regulatory authorities, capital market and medium and minority shareholder? How do market participants react to different adjustment of independent directors? In this paper, we are trying to address these questions.

We motivate this work by investigating the behavior of how companies adjust their independent directors from the perspective of independent directors' background. We find that percentages of independent directors with accounting background increase significantly in mishap companies. We found that 67% of companies' independent directors have accounting background in the event year, while increasing to 78% in the subsequent year. Besides, adding accounting professionals after a mishap can help companies mitigate distress from capital market and medium and minority shareholders, which highlights the supervising role of independent directors with accounting background.

The remaining of this paper is organized as follows. The second section provides institutional background and hypothesis. The third section is data and variables description. The fourth section lists descriptive statistics. The fifth section offers empirical test and explanation. The sixth section concludes the paper.

2. Institutional Background and Hypothesis

2.1. Institutional Background

To put forward in order to further improve the corporate governance structures and promote the standardized operation of listed companies, on August 16, 2001 CSRC issued the guiding opinion on establishment of independent director systems by listed companies, which gave birth to China's independent directors system.

The Guidance requires independent directors with strong economics and law background. In particular, one of them should be accounting expert. Nevertheless, little rigid requirement is addressed on the specific background of independent directors; people who can satisfy as an independent director are not rare. Thus, independent directors can be from various industries with different background, playing their own distinct role in companies. The Guidance requires listed companies should establish independent director systems. Besides, CSRS address that an independent director should have the qualifications required to exercise his functions and powers as such a person holding the position of independent director, independent directors must be independent. The nomination, election and replacement of independent directors should be conducted in a legal and standardized manner [4].

Lou [5] documented foreign researches and found that independent directors work as supervisors, strategy designers and politicians in companies. Research Center of Shanghai Security Exchange [6] believed that functions of independent directors are supervision, assistance and networking. Zhou [7] considers independent directors serve as supervisors and consultants for listed companies. Due to the inconsistency of original intention on establishing independent system among CSRC, listed companies and independent directors, whether independent directors are competent and willing to work as a supervisor and consultant need further consideration. This paper uses incentive compatibility theory to analyze incentive incompatibility in initial selections of independent directors and incentive compatibility in adjusting after a mishap.

2.2. Incentive Incompatibility: In Initial Selections

Incentive incompatibility is a mechanism design in which conflicting objects exists in principal and agent. Under certain circumstance, agents have no incentive working hard to fulfill principal's goals; what is more serious, agents may choose behaving negligence and profusion in hopes of self-interest maximization.

The controller of such [joint-stock] companies, however, being the managers of other people's money rather than of their own, cannot well be expected, that they should watch over it with the same anxious vigilance with which the partners in a private copartnery frequently watch over their own. Like the stewards of a rich man, they are apt to consider attention to small matters as not for their master's honor, and very easily give themselves a dispensation from having it. Negligence and profusion, therefore, must always prevail, more or less, in the management of the affairs of such a company [8]. China's independent directors system was created from a mandatory institutional change led by CSRC, which gave birth to a special principal-agent relationship — CSRC delegate listed companies to employ independent directors. In this case, CSRC is the principal, listed companies are agent. CSRC, listed companies and independent directors, as the main parties in this mechanism, have different incentive and opinions in the implementation, therefore, Qingquan Tang [9] analyze the three incentives. CSRC's incentive is optimizing board structures in listed companies, protecting interest of medium and minority shareholders, improving information disclosure and internationalization. From the view of listed companies, they induct independent directors in hopes of improving company's image and decision-making ability, dealing with challenges and conquering financial stress. Speaking of independent directors, this invitation means not only get paid and easier to fetch resources, but also reputation and self-fulfillment.

Obviously, incentive conflictions among CSRC, listed companies and independent directors bring disagreement to the establishment of independent directors system. Referring to the consultant role, incentive confliction doesn't exist. In detail, independent directors provide listed companies with strategic, political and networking assistance by using "knowledge capital" of their own, which creates promotion to company's performance. As a result of that, independent directors will enjoy higher reputation and compensation. Here is a "trilateral win contract", which indicates the realization of incentive compatibility. There are conflict incentives of the three parties in independent director's "supervision role". For one thing, there is incentive conflictions originated from the selection mechanism. The reality that independent directors are nominated by majority shareholders in most Chinese listed companies determines that independent directors cannot stand in medium and minority shareholder's shoes as CSRC expected, otherwise incentive incompatibility will come into being. Secondly, the compensation mechanism in independent directors system brings incentive conflictions. It is the listed company controlled by the first majority shareholder and management who pays for independent directors, but the main duty them is supervising the company. In conclusion, regulatory authorities expect independent directors serve as a compatible supervisor; nevertheless listed companies don't want to see that condition happens by no means, they hope independent directors are only consultant rather than watchdog, which shows the incentive incompatible in the selection of independent directors between the principal (regulatory authorities) and agent (listed companies).

2.3. Incentive Compatibility: Adjustment after the Mishap

In mechanism design, a process is said to be incentive compatible if all of the participants fare best when they truthfully reveal any private information asked for by the mechanism. As an illustration, voting systems which create incentives to vote dishonestly lack the property of incentive compatibility. In the absence of dummy bidders or collusion, a second price auction is an example of mechanism that is incentive compatible.

Listed companies wish independent directors to be consultant rather than supervisor. This intention is one-sided romance to some degree because the Guidance requires at least one accounting professionals should be presented as an independent director. What's more, listed companies cannot dominate the selection confronting with pressures from medium and minority shareholders, regulatory authorities and capital market. More and more challenges are heard these days focusing on the issue independent directors are not independent, with little awareness neither. The emergence of independent directors system is to protect medium and minority shareholders, but what we can see is quite different from what we hoped. Lack of independence means independent directors are controlled and manipulated by majority shareholders. Meanwhile, lack of awareness means they cannot satisfy the general public as integrity and competent professionals. Anecdotal evidence shows that independent directors will not only be challenged medium and minority shareholders, regulatory authorities, but also punished by law in serious circumstance after a mishap. Thus, listed companies will adjust independent directors after a mishap hoping to mitigate distress from capital market and medium and minority shareholders, hence, incentive compatibility happens.

2.4. Hypothesis

As the independence of independent directors is difficult to measure, this paper mainly test the awareness of them (*i.e.* competence and motivation of independent directors). Jensen and Meckling [10] analyze how the cost of transferring specific knowledge encourages the decentralization of decision rights and how this decentralization generates the rights assignment and control problems. They pointed out that ignoring agency problem, assigning decisions rights to individuals who have the decision-relevant knowledge and abilities increases efficiency. Self-interest on the part of individual decision makers, however, requires a control system to motivate individuals to use their decision rights optimally. This paper uses professional knowledge as a proxy to measure occupational competency of independent directors [7].

We believe that independent directors with accounting background are accomplished in solving financial problems, while management and technical knowledge will provide companies with helpful suggestions on operating performance. A body of foreign researches supports that independent directors with accounting background play a vital role in eliminating earnings management and fraud [11-13]. The Sarbanes-Oxley Act of 2002 and the Guidance emphasize the importance of independent directors with financial background. Johnson [14], Anderson and Bizjik [15] and Zhao *et al* [16] find independent directors with management background will improve companies operating performance. Therefore, this study empirically tests the following hypothesis:

Hypothesis 1: listed companies will increase the number of independent directors with accounting background after a mishap.

Fama and Jensen [17] argue that outside directors tend to be more effective monitors of management than inside directors because they are generally key decision makers at other organizations who are concerned about their reputations in the managerial-labor market. According to their argument, outside directors signal their abilities as key decision makers through their board decisions. This study uses reputation to proxy independent director's occupational motivation and will empirically tests the following hypothesis:

Hypothesis 2: listed companies will increase the number of independent directors with higher reputation after a mishap.

Gordon [3] point out that independent directors as developed in the U.S. context solve three different problems: First, they enhance the fidelity of managers to shareholder objectives, as opposed to managerial interests or stakeholder interests. Secondly, they enhance the reliability of the firm's public disclosure, which makes stock market prices a more reliable signal for capital allocation and for the monitoring of managers at other firms as well as their own. Third, and more controversially, they provide a mechanism that binds the responsiveness of firms to stock market signals but in a bounded way. The turn to independent directors serves a view that stock market signals are the most reliable measure of firm performance and the best guide to allocation of capital in the economy, but that a "visible hand," namely, the independent board, is needed to balance the tendency of markets to overshoot.

How do investors react to adjustment to independent directors after a mishap, to specify, increasing the number of independent directors with accounting background or increasing the number of independent directors with higher reputation? In this paper, we will empirically test this question. Thus, we develop the following hypothesis on firm's market performance.

Hypothesis 3: listed companies will enjoy positive contemporaneous return after adjusting independent directors after a mishap.

3. Data and Variables

This part is organized as follows. First of all we will provide an introduction to the types of independent directors listed companies appointed, and then we will empirically test how companies adjust independent directors after a mishap. Different independent directors play various roles due from their functions and positions. Our test focuses on the background of independent directors.

3.1. Sample

In this paper, our mishap companies during the year 2002 to 2004 are selected according to companies' annual report, announcement and other information. Independent directors' background and characters of companies (especially for important bad news) are obtained from WIND and CSMAR database. Other data are collected by hand.

3.2. Variables

Our empirical study comprises three groups of variables: independent directors' Specialties, reputation and companies' mishap.

3.2.1. Variables about Independent Directors' Specialties

Independent directors' majors can be divided into four categories: economics and management, accounting, law and technique, which correspond to four dummies in our paper. The Guidance requires at least one accounting professionals should be presented as an independent director. To better investigate the adjusting of accounting professionals in listed companies, we design a continuous variable to depict percentage of accounting professionals. Panel A in **Table 1** presents variables about independent directors' background.

3.2.2. Reputation Variables of Independent Directors

Reputation is hard to be quantified. Some scholars use the average number of companies in which a person serve as an independent director as a proxy for reputation [16,18,19]. Actually, some prestigious independent directors are reluctant to accept more invitations, which highlight the deficiency to this method. To be objective, we use Xia *et al*. [20] and Wei [21] for reference and add some improvement to the method. We use expert assessment to evaluate independent directors' reputation. Panel B in **Table 1** presents variables about independent directors' reputation.

3.2.3. Mishap Variables

Different kinds of mishap can be invasion to medium and minority shareholders interest. This paper chooses punishment from regulatory authorities and qualified audit opinions as proxy for important mishap. The former in dicates fraud in listed companies while the latter means problems in financial reports. Two types of mishap are closely related to companies' financial reports, which

Table 1. Variable definations.

Variable Name	Abbreviate	Definition
Panel A: variables about independent directors' knowledge background		
Accounting	ACCO1	If an accounting professional is appointed, ACCO1=1, otherwise ACCO1=0
Percentage of accounting	ACCO2	Number of independent directors with accounting background/Number of independent directors
Law	LAW	If a law professional is appointed, LAW=1, otherwise LAW=0
Economics and management	ECON	If an economics and management is appointed, ECON=1, otherwise ECON=0
Technical	TECON	If a technical professional is appointed, TECON=1, otherwise TECON=0
Panel B: variables about independent directors' reputation		
Reputation	REPUT	Average score, calculating process: how many companies a person serves as an independent director (40%), reputation of his afflation (20%), position (20%), professional title (10%) and education degree (10%)
Panel C: Definition of conviction events in mishap companies		
Conviction	UNRULE	Punished by regulatory authorities or receiving qualified audit opinions

have a name "conviction events". Panel C in **Table 1** presents variables about mishap.

4. Descriptive Statistics

4.1. Status Quo of Independent Directors

The independent director system in China is basically driven by mandatory rules rather than spontaneous institutional change promoted by listed companies and general public. Therefore, majorities of listed companies carry it into execution by "the last bus". **Table 2** reports the general situation of independent directors in china's listed companies. Only 325 companies have independent directors in 2001, covering 28.56% of china's listed companies. From 2002 on majorities of china's listed companies put the system into practice. On average, Boards are reelected every three years. **Table 2** shows that the number of independent directors decreased in 2005 compared to 2004, indicating that a body of listed companies reelected during 2004 and 2005. Therefore, we restricted our target sample mishap companies from 2002 to 2004, corresponding to reelection year. Data related to independent directors' background spans from 2002 to 2005.

Table 2. Status quo of independent directors.

Year	Listed companies			Independent directors	
	Number	*Appointing independent directors*	*Percentage*	*Number*	*Average*[1]
2001	1140	325	28.56%	741	2.28
2002	1204	1175	97.59%	2679	2.28
2003	1267	1261	99.53%	4035	3.20
2004	1354	1353	99.93%	4506	3.33
2005	1351	1351	100.00%	4461	3.30
Total	6316	5465	86.52%	16422	3.00

4.2. Statistics Relating to Independent Directors' Background

Our data covers independent directors' background from 2002 to 2005.

4.2.1. Statistics of Independent Directors' Specialties

Table 3 reports distribution of independent directors' specialties. Independent directors with economics and management specialties represent 27% of all directors, while technicians cover 23% and 11% for that of law in 2002. Obviously, the phenomenon that independent directors with economics and management majors or with accounting background holding concurrent posts in different companies is not rare. Accounting professionals and law experts are increasing year by year; percentage grows from 27% in 2002 to 28% in 2005 for accounting professionals, from 11% in 2002 to 13% in 2003 for law experts respectively.

4.2.2. Statistics of Independent Directors' Reputation

This paper uses expert assessment to evaluate independent directors' reputation. How many companies a person serves as an independent director, reputation of his own afflation, position, professional title (or education degree) are four proxies for reputation, each of them has their own weight, which are 40%, 20%, 20%,10% and 10% respectively. Full mark is 5 points. **Table 4** reports scores of independent directors' scores. On average all of them are larger than 1, [1,2) covers 8.4% of the whole sample, [2,3) covers 65.0% , [3,4) covers 22.0%, while [4,5] covers 5.7%. Due to strict assessment, few independent directors' reputation scores [4,5], which doesn't influence the accuracy of the final result.

Table 3. Independent directors' specialties.

Year	2002		2003		2004		2005		Total	
Acc	727	27%	1092	27%	1236	27%	1249	28%	4304	27%
Law	295	11%	525	13%	582	13%	608	14%	2010	13%
Econ	1035	39%	1500	37%	1681	37%	1646	37%	5862	37%
Tecon	622	23%	918	23%	1007	23%	958	21%	3505	22%
Total	2679	100%	4035	100%	4506	100%	4461	100%	15681	100%

Table 4. Distribution of independent directors' reputation.

Year / Reputation	2002		2003		2004		2005		Total	
Missing	11	0.40%	5	0.10%	5	0.10%	5	0.10%	26	0.20%
[0，1)	0	0.00%	0	0.00%	f0	0.00%	0	0.00%	0	0.00%
[1，2)	218	8.1%	335	8.3%	380	8.4%	381	8.5%	1314	8.4%
[2，3)	1769	66.1%	2592	64.3%	2884	64.0%	2936	65.8%	10181	65.0%
[3，4)	571	21.3%	929	23.0%	1013	22.5%	932	20.9%	3445	22.0%
[4，5]	108	4.0%	352	8.7%	221	4.9%	206	4.6%	887	5.7%
Total	2677	100%	4033	100%	4503	100%	4460	100%	15673	100%

4.2.3. Statistics of Conviction Event

As is known to all, china's stock market is still in the infancy period and institution investors need great improvement in the days to come. Thus, irregular events are not rare. Punishment from regulatory authorities and qualified audit opinions from public accounting firm can be seen each year in capital market, which indicates serious financial problems in listed companies. **Table 5** presents conviction events (*i.e.* punishment from regulatory authorities and qualified audit opinions from public accounting firm) in listed companies.

5. Empirical Test and Explanation

5.1. Descriptive Statistics of Adjustment

We develop T-test and Z-test to find the difference of independent directors in event year and subsequent year. Panel A of **Table 6** reports the results. Percentages of independent directors with accounting background increase significantly in mishap companies. 67% of companies' independent directors have accounting background in the event year, while increases to 78% in the subsequent year, which is significant at 1% level. Accounting directors covers 26.63% of all external directors in the conviction year, while increases by 2.57% to 29.2%in the subsequent year, significant at 10% level. Results indicate that companies increase accounting professional as independent directors after a mishap. However, empirical results indicate that listed companies do not increase independent directors with other background (e.g. economics and management, law and technology). Accounting professionals are exerted in figuring out financial problems. Companies appoint them to mitigate distress between regulatory authorities and minority shareholders, providing positive signals to the general public. Actually, foreign and domestic researches emphasize the importance of accounting independent directors. Xie *et al*. [11], Bedard *et al*. [12] and Bryan [13] find that independent directors with financial background play a vital role in supervision and restriction of management earnings management.

Table 5. Conviction event in China's listed companies.

Variable	2002	2003	2004	Total
UNRULE	157	111	164	432

Besides, statistics shows that average score of independent directors' reputation in mishap companies is 2.5646 in the conviction year, while decreases to 2.55 in the subsequent year. No statistic evidence supports our second hypothesis. The reason listed companies don't increase the number of independent directors with higher reputation after a mishap is two folded. For one thing, higher reputation doesn't predict more competence. Anecdotal events in capital market show that "vase directors" not only means incompetence but also dereliction of duty. Lu Jiahao in "Zhengbaiwen Event" is a persuasive and vivid example for us. Wang *et al*. [19] find independent directors' reputation improves company's performance significantly but Zhao *et al*. [22] supports that independent directors' reputation doesn't improve family firm's performance significantly. No evidence shows that reputation backs up independent directors as a competent supervisor. Zhou [7] and Zhou *et al*. [23] are motivated by their reputation, rather than restricted.

Table 6. Independent director adjustment in event year and subsequent year.

Variable	Event year			Subsequent year			T-test	Z-test
	N	*Mean*	*Median*	*N*	*Mean*	*Median*		
Panel A: background of specialties								
ACCO1	432	0.6728	1	423	0.7801	1	−3.54***	3.51***
ACCO2	432	0.2663	0.33	423	0.2920	0.33	−1.75*	1.83*
LAW	432	0.3921	0	423	0.4397	0	−1.41	1.41
ECON	432	0.7517	1	423	0.7683	1	−0.57	0.64
TECON	432	0.4316	0	423	0.4704	0	−1.14	0.57
Panel B: background of Reputation								
REPUT	432	2.5646	2.55	423	2.5613	2.55	0.12	−0.98

***, **, and* represent significance levels at the 1%, 5%, and 10% levels, two-tailed, respectively. Independent directors' specialties data are unavailable for 9 mishap companies.

Table 7. Discriptive statistics of accounting independent direcors by year.

Year	N	ACCO1		ACCO2			ACCO1		ACCO2	
		Mean	Median	Mean	Median		T-test	Z-test	T-test	Z-test
2002	1135	0.59	1.0	0.26	0.33					
2003	1248	0.76	1.0	0.27	0.33	02&03	−9.15***	−8.99***	0.02	−0.96
2004	1347	0.79	1.0	0.27	0.33	03&04	−1.42	−1.42	−0.65	−0.35
2005	1329	0.78	1.0	0.28	0.33	04&05	−1.02	1.02	−0.93	0.89

***, **, and* represent significance levels at the 1%, 5%, and 10% levels, two-tailed, respectively.

Secondly, unqualified opinions from external auditors indicate deficient in companies, therefore, there is no reason for prestigious people to accept invitation from mishap companies for the sake of avoiding risk.

5.2. Robust Tests: Is That Resulted from Institutional Change

Implementation of independent directors system in China is a progressive process. The Guidance requires independent directors should be included in the board before July 30, 2002. Besides, at least one third directors in the board should be external directors, one of whom should be accounting expert. Obviously, companies increase accounting directors to meet the mandatory requirement from 2002 to 2003. Does the increase result from institutional change? We will develop additional test in the following. **Table 7** reports descriptive statistics on independent directors' accounting background. Result shows that percentage of companies in which accounting experts present as an independent directors are 59% in 2002, while 76%, 79% and 80% for the year 2003, 2004 and 2005 respectively. Besides, empirical evidence point out that percentage of companies in which accounting experts present as an independent directors increases from 2002 to 2003 significantly in 1% level. However, the percentage increases insignificantly by year from 2003 to 2005. Thus, listed companies appoint more accounting expert as independent directors not only because of their own demand, but also consequence from institutional change. Besides, nonparametric test shows that percentage of independent directors with accounting background in companies doesn't increase year by year from 2002 to 2005, which indicates that the increase in mishap companies are not resulted from institutional change. In conclusion, our result is robust.

5.3. Adding Accounting Independent Directors is Helpful for Market Performance

Empirical evidence shows that China's listed companies will add accounting professionals as their independent directors, however, whether they can benefit from this choice need further investigation. We use market adjusted model to calculate cumulated abnormal return (CAR thereafter), which are computed as the stock's raw return over the interval minus the corresponding equally-weighted market return. We selected 70 companies which add accounting independent directors after the mishap. **Table 8** shows that they experienced negative CAR 2 years before the conviction and significant in 1% level, but CAR is negative but insignificant during the conviction year. After the mishap, market performance increase year by year. We may infer that mishap companies enjoy market performance improvement by adding accounting independent directors. Accounting professionals are favored by market participants.

Barth *et al*. [24] developed a cross-sectional model to test whether improvement in company's market performance benefits from increasing in brand value. To investigate correlations between market return and change in brand value, company's contemporaneous return is regressed on net income, change in net income compare to last year and change in brand value. The coefficient of change in brand value defines the correlation between market return and change in brand value.

We are trying to investigate the correlation between market return and whether mishap company adding accounting independent directors, so we introduce a new dummy *addacco*. New model is shown as follows.

$$RETURN_{it} = \delta_1 NI_{it} + \delta_2 \Delta NI_{it} + \delta_2 addacco_{it} + \varepsilon_{i,t} \quad (1)$$

$RETURN_{i,t}$ denotes firm i's contemporaneous return in year t. The deadline of China's listed companies' annual report is April 30th in the subsequent fiscal year, therefore, we use the first trading day in May in the fiscal year as our beginning date for contemporaneous return. $NI_{i,t}$ is net income per share (extraordinary items are excluded), and $\triangle NI_{i,t}$ denotes change in net income compare to last year. *Addacco* is a dummy, which equals 1 if mishap company adding an accounting independent director, 0 otherwise.

Table 9 reports our OLS regression result. Empirical result shows that net income per share (extraordinary items are excluded) is highly correlated with contemporaneous return, adding accounting independent director help companies improve their market performance significantly (the coefficient of *addacco* is 0.2179, significant at 0.01 level). Accounting professionals can help mishap companies mitigate distress from capital market and medium and minority shareholders, which highlights the supervising role of independent directors with accounting background.

Table 8. Descriptive statistics of car around the mishap.

	N	Mean	Min	Max
CAR[–750, –500]	70	–0.0739**	–1.1414	0.4204
CAR[–500, –250]	70	–0.1837***	–0.9635	0.3005
CAR[–250,0]	70	–0.3021***	–1.0568	0.7177
CAR[0,250]	70	–0.0890	–1.8013	1.8653
CAR[250,500]	70	0.0894*	–0.8915	0.9016
CAR[500,750]	70	0.6382***	–0.5249	3.9936
CAR[–750, –500]	70	–0.0739**	–1.1414	0.4204

***, **, and* represent significance levels at the 1%, 5%, and 10% levels, two-tailed, respectively.

Table 9. OLS regression examining whether market approves adding accounting independent directors.

Independent Variable	Dependent Variable		
	Predicted sign	*Coeff.*	*t-Stat.*
Intercept	?	−.6109	−13.53***
NI	+	.4665	4.58***
△NI	+	.0019	1.36
Addacco	+	.2179	2.63***
Number		417	
Adjusted R^2		0.24	

***, **, and* represent significance levels at the 1%, 5%, and 10% levels, two-tailed, respectively.

6. Conclusions

This paper investigates the behavior of how companies adjust their independent directors from the perspective of independent directors' background, by using data of Chinese listed companies to which a mishap happened between 2002 and 2004 as our target sample. Evidence shows that listed companies will increase independent directors with accounting background significantly after a mishap (*i.e.* receiving qualified audit opinions or punished by regulatory authorities). Nevertheless, listed companies don't increase the number of independent directors with higher reputation after a mishap. On one hand companies don't resort to prestigious independent directors for assistance, and on the other hand prestigious independent directors don't want to work for mishap companies. Empirical evidence shows that listed companies will increase independent directors with accounting background after a mishap for the purpose of mitigating agent distress between majority shareholders and minority shareholders, enjoying significantly positive cumulative abnormal return after the adjustment in the long window. Our result indicates that listed companies will increase accounting independent directors for the purpose of mitigating distress from capital market and medium and minority shareholders, which highlights the supervising role of independent directors with accounting background.

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J. Service Science & Management, **2010, 3, 345-351**
doi:10.4236/jssm.2010.33040 Published Online September 2010 (http://www.SciRP.org/journal/jssm)

Pricing Services in a Grid of Computers Using Priority Segmentation

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Received May 27th, 2010; revised July 1st, 2010; accepted August 6th, 2010.

ABSTRACT

In the past decade many grids of computers have been built among non-profit institutions. These grids are built on a voluntary participation and the resources are not charged to the users. When a resource is given free of charge its allocation is in general not optimal. In this paper, we propose an original mechanism that allows an optimal resource allocation without cash exchanges. We develop a pricing scheme where the service is segmented according to the priority level. The optimal prices of the different services are obtained by solving a Markov Decision Process (*MDP*)*. Each participant receives a credit that is proportional to its contribution that enables him to have access to services offered by the grid.*

Keywords*: *Service Pricing, Grid Economy

1. Introduction

Grid computing has become increasingly important in recent years with ever increasing demand of computing and storage resources [1].

Sharing, selection and collection of geographically distributed resources such as super computers, storage systems, data resources and specialized devices are made possible by grid network for solving large-scale resource-intensive problems in science, engineering and commerce. Organizations that are looking for extremely high computing power for short periods of time, but which do not necessarily want to invest further in their own computing resources are finding grid computing as an attractive alternative. Several large firms such as IBM, Unilever, Ericsson and Hitachi are investing large sums of money in developing grid computing initiatives [2].

The idea of creating a grid to share resources which seems to be very intuitive now was originally borrowed from electrical power grid. In the mid-1990 scientists began to explore the design and development of an infrastructure which was analogous to electric grid due to its pervasiveness, ease of use and reliability [3]. The motivation for computational grids was initially driven by large scale, resource-intensive (computational and data) scientific applications that require more power than a single computer (PC, workstation, supercomputer, or cluster) [1].

In most grid projects, the connected PCs are generally made available at no cost. Indeed it serves the needs of research projects requiring huge computing power. However, economic theory tells us that if prices are set in a fair manner between the provider and the user of the service, this should lead to an optimal allocation of resources. For users, the value of a grid is higher than its accounting value. Indeed, the grid offers more than software and hardware: it offers a service. In practice, the pricing of services is mainly based on the cost structure, which does not take into account the real value provided to the client.

In this paper, we propose an original mechanism that provides an optimal resource allocation without involving cash exchanges. We propose a pricing scheme where the service is segmented according to the notion of priority level. The optimal prices of the different services are obtained by solving a Markov Decision Process (MDP). Each participant receives a credit that is proportional to its contribution that enables her/him to have access to services proposed by the grid.

This paper is organized as follows. In Section 2, we present the particular nature of grid pricing services. In Section 3, we explain notions of market based resources in the context of shared grid computing. In Section 4, we present the pricing model using priority segmentation. In

Section 5, we illustrate our model with a simple instance and present numerical results. Finally, in Section 6, we indicate further research directions.

2. Service Proposal and Pricing for Grid Users

What could be done for pricing grid services? Most of the pricing techniques applied to the service sector are devoted to service commodities like airplane seats or hotel rooms. Service activities are traditionally described with the help of the IHIP paradigm (intangibility, heterogeneity, instantaneity and perishability). Intangibility and heterogeneity make the pricing scheme not easy to model services. The pricing of a service relies upon three pillars: internal organizational costs, the competitors' prices and the perceived value by the customers. In this research, we focus our attention on the latter, *i.e.* the value perceived by the customers in the service experience.

As a matter of fact the question of pricing is essential to analyzing the system of service production. Pricing directly impacts how the service is positioned, and influences equally how clients and coproducers will interact. The paradigm of the price/quantity economic model cannot be fully realized in the service world, however. Quantity is replaced by the idea of value perception, which naturally impacts the conventional production model.

Grid services fall in the category of knowledge based services. Consequently, a service plan based on know-how and expertise depends on the following: a thorough and clear understanding of the needs and expectations of clients, the ability to elaborate a diagnosis of client needs from limited information, the outline of a specific service proposal, the efficient use of delivery processes and of existing products (or product modules), and finally a custom-made solution that incorporates perceived value-added (often referred to as problem resolution).

Very often, delivering more value in the knowledge-based services means delivering more tangibility and more customization. Customization has been defined as the ability of the service delivery system and its employees to attend flexibly to customer needs [4]. Customization may also induce more risky operations as services would become inherently variable in how they are conducted, and according to [5], it is to be expected that problems will occur. Therefore, how to make attractive and price service operations that increase tangibility and customization for the customer while reducing (or maintaining) the complexity of managing real heterogeneity?

In recent research, we are exploring the potential pricing schemes that could be established and the relevant criteria that should be used to determine a fair price in the context of grid services taking into account the point of views of providers and consumers of knowledge-based services. To answer to this question, we must develop a grid service model based on the main attributes (also called salient attributes of the service in the share of choice model terminology [6]) as perceived by the user. In our case, we could retained several attributes such as the capacity made available to the user (three formats -small, medium and large), the proper priority management of jobs executed (the objective that is to be retained in the model presented hereafter), or reporting relevant information to the users. In this paper we will assume that priority management is a salient attribute of grid services, which is perceived as important in terms of value. However it is clear that in a subsequent research, we need to investigate through survey techniques what represent the most important salient attributes for grid users.

In this project, we intend to develop a pricing scheme based on the perceived value by the user of an actual grid application. This contribution is based on interdisciplinary research. Indeed, our pricing model essentially borrows academic findings arising from Marketing and Service Science. The solution relies on a number of different fields: Operations Research, Game Theory and Negotiation Theory. We can consider three cases that are relevant for different situations: 1. the grid is managed by a central agency, 2. the actors in the grid are competing without cooperation, 3. the actors in the grid are competing but cooperation is possible.

In this paper, we will solely tackle the case where the grid is managed by a central agency. For instance, we have already explored the shadow prices approach through an optimization problem called the share of choice model [6]. This latter model attempted to optimize the design of a service by selecting its attributes according to the perceived value of a sample of clients. Perceived values were expressed as utility functions obtained from conjoint analysis. Conjoint analysis techniques permit the construction of path-worth or utility functions for each respondent regarding the different attributes of the service.

Regarding what has been presented, our goal is to compute a price for the utilization of the resources such as CPU, RAM, bandwidth, libraries, etc. However, the price will be differentiated as a function of the quality of the service (in particular, privileged users that can have priority for their jobs) and also as a function of the level of demand (different prices for rush hours and off-peak hours).

3. Market Based Resource Management

There has been extensive research on how to manage the resources in an efficient way, optimize its usage, balance the load and reach maximum user satisfaction. Sharing resources fairly with economic efficiency, where efficiency can be defined as ratio of the actual total benefit for all users to optimal total benefit, at a low cost still remains a challenge [7]. The fact that consumers have different goals, preferences and policy further adds to the complexity of resources management [8]. Software agents such as automatic scheduling programs and negotiation agents can play an essential role in realizing this vision of the grid. Numerous economic models for grid resource management such as commodity market models, auction, contract-net/tendering models, bargaining models, posted price models, bid-based proportional resource sharing models, cooperative bartering models, and monopoly and oligopoly had been proposed in the literature [9]. While some of the more commonly referenced work focused on commodity markets, auctions and fixed budget based marketing mechanism for the resource management [10], auctioning has long been an important aspect of many economies. Indeed, it provides a fair trading environment as a decentralized structure, are easier to implement than other economic models and respect the autonomy of resource owners [11]. In Another variant of auctioning fixed budget mechanism efficiency and fairness of the allocation of resources at equilibrium is evaluated through the measures of 'utility uniformity' and 'envy-freshness'. The grid resource allocation model is based on Continuous Double Auctions (CDA). Different scheduling strategies have been analyzed which can be applied by the user to execute workflows in such an environment, and try to identify the general behavioral patterns that can lead to a fast and cheap workflow execution [12].

In history based pricing model consumers and producers determine their bid and Ask prices using a sophisticated history-based dynamic pricing strategy and the auctioneer follows a discriminatory pricing policy which sets the transaction price individually for each matched buyer-seller pair. The pricing strategy presented generally simulates human intelligence in order to define a logical price by local analysis of the previous trade cases. Here the authors employ a continuous double auction protocol as an economic-based approach to allocate idle processing resources among the demanding nodes [13].

In the economic model the center point is the interaction between grid users and providers. While most market models have been based on auctions, commodity market models have also been interesting research topic. Markets are considered to be based on commodity where applications can treat computational and storage resources as interchangeable and not as specific machines and disk systems. Obviously, prices are a key element of this model [14-16].

An alternative approach to market based and economy based models is finance based model. Various grid resources such as memory, storage, software, and compute cycles are seen as individual commodities and pricing of the resources is done in isolation and in combination of various resources. A quality of service (QoS)-profit equilibrium model has been proposed for pricing grid resources that is based on finance concepts [17].

Two shortcomings in a grid economic environment have been identified in [18]. The first shortcoming is that there are no standards for pricing schemes, caused by a large difference in the units that are traded (e.g. CPU cycles or virtual clusters) in grid computing. The second shortcoming is the lack of models for managing the pricing of intangible elements (e.g. software applications) and computational elements (e.g. virtual machines, which comprise resources such as CPU, memory, disk space, network bandwidth).

3.1. A Pricing Scheme Adapted to the Particular Nature of Grid Services

This paper further presents a pricing service for grid computing services, which resolves these shortcomings by introducing a general pricing scheme for informational and computational elements. We describe the functional requirements, architecture, and the interfaces of the pricing service. The pricing service allows expressing the proposed general pricing scheme as an XML document, which can be linked to the Service Level Agreements (SLA). Contrary to other proposals on pricing, the pricing service is separated from the functionality of metering, accounting, and payment.

Various kinds of solutions to grid resource discovery have been suggested, including centralized and hierarchical information server approaches. However, both of these approaches have serious limitations in regard to scalability, fault tolerance, and network congestion. To overcome these limitations, indexing resource information using a decentralized, for instance peer to peer, network model has been actively proposed in the past few years [19].

A new infrastructure called Grid Bank provides services for accounting of the grid resources thus filling the gap of these needed services. The support of computational economy and accounting services can lead to a self-regulated accountability in grid computing. This paper presents requirements of grid accounting and different economic models within which it can operate and proposes a Grid Accounting Services Architecture to meet them [20].

Practically, we intend to focus on a particular salient attribute of typical grid services which represents in our case an intangible element of perceived value by the user. This makes our approach original compared to previous papers on grid pricing. The salient attribute developed in our model corresponds to the idea that priorities of jobs executed on the grid are most of the time satisfied. Indeed services provide users with benefits that are perceived with more or less value. Consequently, we assume that the management of priorities in the execution of jobs is perceived as an important element of value. In logistic terms, the quality of this management corresponds in the model to our service level. To be able to obtain a pricing strategy leading to the best priority management of jobs executed, we have developed a mathematical programming model. It aims at minimizing inconveniences due to mismanagement of priorities while taking into account grid capacity constraints. As probabilities of a given job being put "on hold" exist, we treat capacity constraints of the grid as a Markov Decision Process (MDP). In the following section, we present the detailed model that we have developed for illustrative purposes.

4. The Model

4.1. Description of the Model

The grid is shared by U different users described by the variable u = 1,..., U. The jobs are classified in J different categories according to the level of urgency. Categories are described by the variable j = 1,..., J. Category j = 1 includes very urgent jobs and category j = J includes job that are not urgent at all. The grid can process jobs with P different priority levels. The highest priority is p = 1 whereas the lowest priority is p = P.

For each user, jobs arrive randomly following an exponential distribution. Let α_{ju} be the parameter of the distribution for the job's category j and for user u. The job's size is random and follows also an exponential distribution. Let β_{ju} be the parameter of the distribution for the job's category j and for user u.

Each user is rewarded at each period with a certain amount of monetary units that permits him to pay the services provided by the grid. Let μ_u be the amount received at each period by user u. This repartition should reflect the contribution of user u to the grid (*i.e.* number of computers, IT specialist, etc. offered by user u to the grid's community).

The services provided by the grid are charged according to the CPU time used and priority level p requested. Let π_p be the price per CPU time for jobs with priority p.

The objective of the grid manager is to provide the best service to the users with the actual capacity of the grid. The service quality is measured by a penalty function, the lowest the function the highest the quality. This function increases each time a job is not completed on time. This function can, for example, measure the percentage of jobs done with a delay. The grid manager has to find the optimal prices π_p in order to have the lowest penalty function.

The objective of the user is to minimize its own penalty function choosing the right priority for each job. They are two possible actions for a user. First, when a new job arrives he has to decide which level of priority will be chosen. Secondly, when a job is in the queue, he can decide to change the level of priority of the job. Of course each decision is taken knowing the load of work of the grid. The set of all possible actions is denoted with A.

4.2. The Model's Equations

This model is described by a MDP where budget constraints are added. The only possibility to solve this enriched MDP is to use the linear programming approach. Value iteration or policy iteration algorithms are not adequate for this enriched MDP.

At this point, we must say that the description of the selfish behavior of each user should be done using Nash equilibrium rather than a MDP. However, this would conduct to a stochastic variational inequality that is very difficult to solve. In order to mimic the selfish behavior, additional constraints are included in the MDP model.

For each user u, let $x(u, j, p)$ be the number of jobs of category j with priority p that are currently in the system. Denote with $S = \{x(u, j, p)\}_{u,j,p}$ the possible states of the system.

Let $q(s, \tilde{s}, a)$ be the generator of the MDP. For the cases $s \neq \tilde{s}$, $q(s, \tilde{s}, a)$ is computed from the corresponding α_{ju} and β_{ju}. For the other cases, we have $q(s, s, a) = -\sum_{\tilde{s}} q(s, \tilde{s}, a)$. It is important to realize that the main difficulty in modeling a MDP is to compute its generator. For example, the capacity constraints of the grid are included in the generator. Modeling capacity constraint in a MDP model is less intuitive than modeling capacity constraints in a linear programming model.

Let $\prod(s,u)$ be the price charged to user u for his jobs that are currently treated by the grid. It depends of course on the prices π_p.

The linear program associated with this enriched MDP is

$$\min \sum_{s,a} C(s,a) \cdot Y(s,a)$$

subject to

$$\sum_{s,a} q(s, \tilde{s}, a) \cdot Y(s,a) = 0 \quad \forall \tilde{s} \in S$$

$$\sum_{s,a} Y(s,a) = 1$$

$$\sum_{s,a} \prod(s,a) \cdot Y(s,a) \leq \mu_u \quad u = 1, \ldots, U$$

$$Y(s,a) \geq 0 \quad \forall s \in S, \quad \forall a \in A$$

The first equations represent the flow constraints and the second equation is the normalization of the probabilities. The last inequalities represent the budget constraints for each user. From this model, the steady state probabilities are computed as follows

$$P(s) = \sum_a Y(s,a)$$

and the optimal policy is given by

$$D(s,a) = \frac{Y(s,a)}{P(s)}$$

$D(s,a)=1$ if policy a is implemented when the state is s (otherwise $D(s,a)=0$). Note that random policies could be possible. In this case we have $0 \leq D(s,a) \leq 1$ and $\sum_s D(s,a)=1 \ \forall s$.

As S has to be finite, we impose reflection conditions on the boundaries. The interested readers can find a detailed description of the modeling methods offered by the MDP paradigm in [21] and [22].

If the prices π_p are taken as a variable, the model is a quadratic program with a non positive definite matrix. In this case, standard software cannot solve the model. To avoid this problem, we consider the prices as parameters. In this case, the model is a linear program that is easily solved if not too big. As the model is not convex in π_p we use a uniform space covering method in order to find the global optimum.

5. Numerical Illustration

The aim of this illustration is to present a numerical application of the general model. Our goal is just to show the efficiency and implementability of the method. We have thus on purpose simplified it. In this small model, we assume to have two categories of jobs: urgent and not urgent ones. We have two kinds of priorities: high and low priority.

This model attempts to describe users that need a huge number of computers for running their jobs. In this example we suppose that each job need the third of the grid resources. This means that maximum three jobs can be processed simultaneously without congestion. In case of congestion, jobs with high priority are processed first. If there are more than 3 jobs with high priority, the last coming jobs are sending in the queue. Doing so, jobs are always processed at full speed or send in the queue.

For this numerical illustration, we assume to have two different kinds of users. The first kind of users expect a lot of urgent jobs that are on average small whereas the second users expect less urgent jobs that are on average big.

In this numerical experiment the objective is to maximize the service level, which is the percentage of jobs that are done without delay.

Table 1 indicates the main parameters employed in the instance developed for the model presented in the previous section. The model was written in AMPL and solved with the software MOSEK. **Table 2** presents the optimal solution for different prices. Prices are given in monetary units per CPU time. We ran the model for more prices but show only few representative results.

We see distinctly that the price policy has an effect on the service level. Indeed, choosing the right prices permits the community to avoid wasting the resources and as a consequence to increase the service quality. In this example, the maximal service level can be attained with several price policies. More than the results, this small model show the applicability of this method.

However, we must emphasize that MDPs are subject to the “curse of dimensionality”. For bigger models, the state’s set S can become too big. In this case it is necessary to reduce the size of the model, applying, for instance, a decomposition and parallel processing method [23].

6. Conclusions and Future Research

In this paper, we propose a new approach to share optimally the resources of a grid of computers. This approach is based on a segmentation of the service where different prices are computed using an enriched MDP model. The method is versatile and can be adapted to numerous problems. Here, the service is segmented accor-

Table 1. Data inputs for the model.

Parameter	Value
$\alpha11$	0.02
$\alpha21$	0.05
$\alpha12$	0.2
$\alpha22$	0.1
$\beta11$	0.005
$\beta21$	0.005

Table 2. Service level for different prices.

Price for high priority jobs	Price for low priority jobs	Jobs on time
1	0.2	97.8%
1	0.4	97.8%
1.2	0.2	91.8%
1.2	0.4	90.2%
1.4	0.6	81.9%
2	0.2	80%

ding to the priority level. The service level corresponds to the percentage of jobs executed without delay, but it could be any other kind of utility functions. As a matter of fact, we have also implemented a more comprehensive model where the service is segmented according to the quality of the computers (speed and size of the memory).

Stochastic models described with MDPs can have a huge size and therefore very difficult to solve. A solution to this problem consists of applying a decomposition and parallel processing method. The structure of the MDP could be exploited to decompose the model into U (*i.e.* the number of users) smaller single user models. These U smaller models are then linked together with a coupling linear program.

As we mentioned earlier, the selfish behavior of each user is mimic including in the MDP model additional constraints. Unfortunately, this way of doing is only an approximation. To perfectly describe this behavior, we should incorporate in the model game theory. The model should be described by a Nash equilibrium rather than a MDP. However, this would lead to a stochastic variational inequality that can be challenging to solve.

7. Acknowledgments

This work has been sponsored by the project Virtual EZ-Grid from the Swiss national fund AAA/SWITCH. A preliminary version of this paper has been presented in the proceedings of IEEE/INFORMS International Conference on Service Operations, Logistics and Informatics. We thank Nabil Abdennadher and Aarti Agrawal for their help.

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J. Service Science & Management, **2010, 3, 352-362**
doi:10.4236/jssm.2010.33041 Published Online September 2010 (http://www.SciRP.org/journal/jssm)

Evaluating Enterprise Risk in a Complex Environment

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Received June 11th, 2010; revised July 19th, 2010; accepted August 21st, 2010.

ABSTRACT

This paper examines the relationship between operational risk management and knowledge learning process, with an emphasis on establishing the importance of statistical and mathematical approach on organizational capability to forecast, mitigate and control uncertain and vulnerable situations. Knowledge accumulation reduces critical situations unpredictability and improves organizational capability to face uncertain and potentially harmful events. We retain mathematical and statistical knowledge is organizational key factor in risk measuring and management process. Statistical creativity contributes to make quicker the innovation process of organization improves exploration capacity to forecast critical events and increases problem solving capacity, adaptation ability and learning process of organization. We show some important features of statistical approach. First, it makes clear strategic importance of risk culture within every level of organization; quantitative analysis support the emergence of latent troubles and make evident vulnerability of organization. Second, innovative tools allow to improve risk management and organizational capability to measure total risk exposition and to define a more adequate forecasting and corrective strategy. Finally, it's not so easy to distinguish between measurable risk and unmeasurable uncertainty, it depends on quantity and quality of available knowledge. Difficulty predictable extreme events can bring out crisis and vulnerable situations. Every innovative approach which increases knowledge accumulation and improves forecasting process should be considered.

Keywords**:** *Complexity, Extreme Events, Operational Losses, Quantitative Management*

1. Introduction

In literature we find out paper explaining mathematical techniques application to operational risk evaluation and other concerning risk management principles and features. What we would like to do in this paper is to merge this too often separated concepts. Thus, in the first part, we describe some aspects of operational risk mainly with respect to relationship between uncertainty and corporate learning process; in the second one, we argue general mathematical approaches implications on operational risk and knowledge management and then we show an innovative mathematical method and exploit its advantages, disadvantages and further extensions.

In modern economic context, knowledge management is a more and more important resource for success of firms. However, getting information is only the first step for a long time sustainable development. In a dynamic system in fact, knowledge may result just a short time vantage because its non-excludability property makes its transfer and competitors' imitation easy [1]. To acquire competitive vantages, firms have to develop and continually improve suitable capabilities and organize routines to control, manage and use the knowledge in a profitable way [2].

Thus, knowledge management becomes progressively the success key for securing organization's sustainability [3], even if a successful learning process needs a good adaptation capability at the same time. Only a supple firm is able to adapt its cognitive patterns to environment and market changes [4] quickly and properly enough to develop an effective generative learning process for new knowledge creation [5]. Knowledge management is a dynamic capability [6]; a successful strategy in the short term may become less efficient in the long one if the firm is unable to increase continually its knowledge, improving competences and innovating competitive advantage.

So we can conclude efficient knowledge management and adaptation capability are both required to organization sustainability. When these conditions are both satisfied, an organization can implement a generative learning process to preserve new knowledge creation and innovation. In this perspective, statistical analysis and mathematical models are some of possible tools which can help firms to improve knowledge accumulation and decision making processes. More and more detailed and reliable forecasting models, in fact, permit to better predict environment changes and manage correlated risk, reducing uncertainty and increasing the organization's problems-solving capability.

2. Organization, Risk and Knowledge

Each enterprise can be thought as a socio-economic organization, headed by one or more persons with a propensity to risk [7,8]. So risk is an integral part of the firm. The increasing complexity of modern society makes risk a particularly critical factor because company management is often unable to face it [9-11]. When we talk about risk we refer in particular to operational risk[1].

If you consider the more and more critical role of risk in company governance, it's easy to understand because overlooking or thinking risks in simplistic way may lead to inadequate exposition or unconscious acceptance by the organization. In contrast, when risk is implemented in the corporate culture, it develops into a production factor and its suitable management becomes an essential part of value creation chain [12]. Just when the concept of risk is integrated in corporate culture, you can identify the basis for prudent and responsible corporate governance [13].

However we need to distinguish between governance and management of business risk. They are two interconnected but different moments of decision-making process. Government takes care of placing the organizational bounds qualifying the logic of value creation and the maximum tolerable risk, while management tends to decompose the overall business risk in a variety of risks, following the stages of assessment, treatment and reassessment of all relevant risk [14].

In other words, risk governance relates to risk culture sharing throughout the all organization as well as to reduce risk overlooking. Risk management relates to every process or technique which allows to mitigate or remove risk for organization. In first instance potential efficient management depend on efficient governance.

Thus, a careful administration of risks leads to some preliminary considerations:

- A corporate governance is based on a complex and dynamic mix of risks linked inextricably to the enterprise system;
- Usually a business risk cannot be fully cancelled;
- Each action to reduce risk exposition involves an organizational cost and brings out other hazards.
- The sustainability of any risk depends on the amount of enterprise knowledge and competences;

Last point focuses on the relationship between risk and knowledge. The risk reflects the limitations of human knowledge or bias, indicating the possible events to which it is exposed due to the combination of their choices, external conditions and the flow of time. Just if knowledge was complete and perfect, firm would operate in conditions of certainty [16]. So risk and knowledge are each other mutually dependent: the risk marks the limit of knowledge and it allows the perception of risk [17]. Over time, the learning process of an organization leads to a better understanding of reality and a more awareness of risk and thus allows to reduce uncertainty and to develop greater risk management and forecasting capabilities.

In literature we found three different approaches which try to define the relationship between knowledge and risk: *scientist current*, *social current* and *critical current*.

The first one is based on logical-mathematical approaches and believes in primacy of knowledge on risk [18,19]. The second one retains limits of knowledge and social interaction processes make the risk a feature of contemporary society, where knowledge contribution merely asserts organizational inability to eliminate risk [20]. The *critical current* based its thesis on knowledge and risk dynamics, where risk cannot be eliminated but it can be reduced or contained [12]; so the learning creative process of a business organization needs to track the business risk, trying to transform or mitigate it through company skills and competences, which organizational knowledge renews over time.

Spread risk culture to any firm level means developing an attitude to adaptation and risk knowledge, looking for useful concepts and approaches to address critical issues of risk assessment and management. Neglecting risks leads the entrepreneurship to a state of myopia that makes it unable to predict or otherwise mitigate critical situations, increasing the vulnerability of all organization, constantly exposed to uncertainty and possible crisis.

The information collection and the learning process, increasing knowledge about nature and behavior of a particular event, can help the ability to manage risks and can play a key role in raising resources, tools or new knowledge which, without allow a precise prediction, will be able at least to reduce risk impact.

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[1]According to Basel Committee [15] operational risk is defined as the risk of loss resulting from inadequate or failed internal processes, people and systems or from external events.

However, the knowledge related to risk management, if misinterpreted, could lead to controversial situations. The larger uncertainty perception is, the stronger will be the people's inclination to not act; in other words, manager who is facing unknown situation usually tends to be more cautious, ready to come back or change his strategy just perceive discrepancy with respect of his expectations. At opposite, when the decision maker believes to know the event distribution, his strategic behavior is determined by a cognitive model built on its previous experience and thus makes him less sensitive to environment changes and to perception of every signal which could prevent or handle unexpected situations (extreme events) and crisis.

3. Crisis Management and Vulnerability of the Organization

We need a more stable and comprehensive concept of crisis in organizations facing complexity and uncertainty as well as a way to reduce risk by better prevention [21].

Crisis management and *vulnerability of the organization* are two very important concepts that have had considerable attention in management literature as the basis for defining processes of contingency planning such as *operational crisis* and *crisis of legitimation* for disaster recovery (bankruptcy, market breakthrough, change in leadership, fraud, etc.). Rarely has it focused on the processes by which the crisis has been generated, its long-term phases and embedded sources [22]. We need to develop a better perspective to explore the generation and nature of crisis events in organizations where, according to Smith [22] "management should not be seen as operating in isolation from the generation of those crisis that they subsequently have to manage, but rather as an integral component of the generation of such events". But we will see that the customer or the user becomes part of the strategic process to prevent and respond to crisis as "partners" of management and shareholders, sharing collective knowledge and information about value creation.

The main factors to create the pre-conditions for crisis and vulnerability of organizations are their *interaction with the market* and the often huge differentiation of this one; the growing importance of *consumer expectations and perceptions* which are closely connected with the image and reputation of the company and of the management; the *technological innovations* and long (or short) wave of change that pushes companies to change rapidly not only their products or markets, but also dealers, managers and organization; the *nature of leadership*, its stability and evolution, as in the case of a jump in family control or a huge change of shareholders [23].

For those reasons and many others that serve to create a complex portfolio of potential crisis scenarios, is necessary to outline the nature of the *crisis management process* and to know how the crisis evolve.

In the literature we can identify a focus on the development of contingency plans to cope with a range of crisis scenarios in terms of response teams, strategies for continuity service provision, and procedures to protect organizational assets and damage limitation. These are activities very important in stopping dangerous consequences of a crisis, but not useful to avoid it, as in the case of an organization's reputational harm, often irreversible. Effective crisis management should include a diffuse and systematic attempt to prevent crisis by occurring [22,24,25].

According to many authors, the *notion of crisis* starts from a circularity and interaction between different process stages not always linearly connected: crisis management, operational crisis, crisis of legitimation, process of organizational learning. In that view, a good preventative measure is *creating resilience* [21,25,26,27, 28]. This can be achieved within the organization by:

- trying to eradicate error traps as a path to explorative learning;
- developing a culture that encourages near-miss reporting;
- dealing with the aftermath of crisis;
- learning lessons from the event;
- defining an accountability to connect stakeholders for crisis potential [26,27].

According to Smith [22] we need a shift in the way of representing organizations' dynamic change and processes of management (before, during and after crisis) as nonlinear connections in space and time. This would allow us to explore *pathways of vulnerability and erosion of defences* (**Figure 1**):

1) *Crisis of management*: the problems are well known; managers believe that their organizations are safe, secure and well run because their short-term perspective sees the comparison between the cost of prevention and perceived costs of limitation and recovery derived from an underestimation of the second in respect to the first. The long-term view for many managers is rare, and often "hostages" of operational phases and controls are bypassed.

2) *Operational crisis*: many characteristics of the crisis are here often visible, but in many cases, contingent and temporarily defined. But we face often situations of deep incubation or latent conditions of crisis factors as if the organization is living in a permanent present, without a

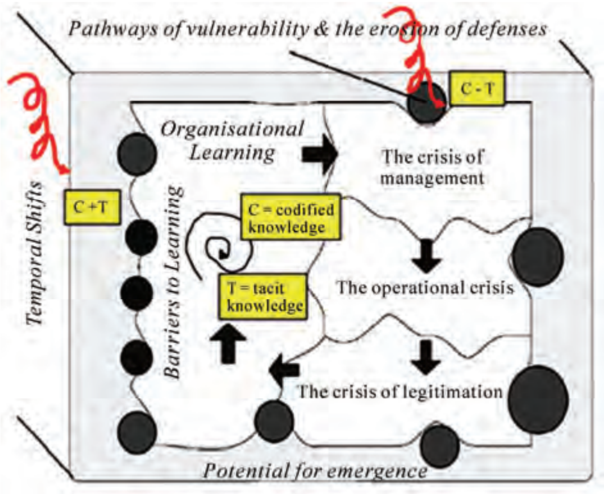

Figure 1. The nature of the crisis management process and the potential for emergence [22].

past and without a future.

3) *Crisis of legitimation*: it starts internally but with immediate external effect attracting media coverage, governmental intervention or public inquiry as in the case of the recent bank crisis in Europe or great companies in USA. It could start from a failure in a specific product or service that causes a loss of customer confidence (and/or shareholders as well). At the same time, it will lead to erosion of the demand and probably to financial instability in the long run, with an impact on stability of shareholders and larger stakeholders too. The organizational learning will show a probable great fragility.

4) *Processes of organizational learning*: a crisis of legitimation leads to a crisis of procedure and practices and then to the lack of confidence of the middle management

5) *Crisis of interchange between tacit and codified knowledge*: we can underline the role of knowledge diffusion as a factor of crisis in case of *overestimation of codified knowledge* with respect to tacit ones, considered as residual errors to remove by a hierarchical control mechanism. Interdependences between tacit and codified knowledge (or between voluntary and involuntary behavior) are the link with the past and future of the company. They represent both the main source of strategic competences in connection with its identity, and the architecture of organizational learning able to sustain more generations of entrepreneurs and managers as well as customers. This is key to describing one of the *pathways of vulnerability*.

Critical situation can be due to a lot of internal and external factors. Bad managed critical situation can turn into organizational crisis. Every risk, extreme event and uncertain situation, which cannot be forecasted, mitigated and controlled, is a potential factor of vulnerability and crisis for organization. It's important to exploit every innovation and tool which can make management process easier, more reliable and more responsible.

4. Certainty, Uncertainty and Risk in Decision Making

In economic context there are measurable uncertainty and unmeasurable uncertainty. If nothing you can say about uncertain event, risk may be thought as a measureable uncertainty. Catastrophic event (rare event) is intermediate situation, it's not a fully unmeasurable uncertainty but an accurate foreseeing could be hard.

Extreme event is located in tails of distribution, it's featured by low probability of occurrence and high negative impact. No information on past behavior allow to exactly understand its dynamic evolution and consequently risk managers are unable to forecast it.

However mathematical models or statistical tools are not so useless as a lot of authors believe, if you judge they allow increasing knowledge accumulation. Better is your knowledge about a phenomena, better you can face it. According to Epstein [29] you can say *a priori* whether a risk is measurable or unmeasurable, it depends on the knowledge and information you have about it. For example, we are not yet able to predict an earthquake but we have learned to distinguish the potentially seismic zones according to their geological composition, to build using materials and techniques which sure high seismic resistance. Thus was possible on base of statistical analyses which allowed to verify where earthquakes happened with larger probability rate and to value the capacity of some materials to respond efficiently to stress actions. In other words, even if you cannot predict a catastrophic event, you can study its features and improve organization capability to adequately face it and to act fast and efficiently to reduce its impact when the event occurs.

In front to these situations, manager can choice different strategies. He may decide on responsible management of every risk or only more ordinary risks accounting. Many decision makers tend to overlook highly improbable events, though very dangerous; most of them usually think coverage costs related to the extreme event prediction are in the time higher than costs needed to face their occurrence. Probability estimation for an outcome based on judgment and experience may result successful but it depends on entrepreneurship or management capability and competence and in uncertain case on randomness. Mathematicals and statisticals allow to get an objective and more adequate probability estimation. Use of statistical techniques for objective management of risks effects on organizational culture and enhance predictive capacity at every firm's level.

However, neglect to study extreme event distribution slows knowledge learning process and reduces organization' absorptive and adaptation capability.

Then overlooking behavior attends a high risk propensity of management and thus reflects negatively on the corporate culture, reducing liability and risk awareness and exposing the company to a higher probability of harmful events occurrence in the long time.

Knight [30] claimed "*there is no difference for conduct between a measurable risk and unmeasurable uncertainty*". Risk management doesn't mean necessarily to consider every potential risk, it regards awareness concept. Prudent management suggests you can choose to apply corrective measures and mitigation actions or rather decide consciously to neglect any specific risks. What is important a manager should make decisions within a rational and responsible approach based on probability of occurrence, predictability and impact estimation.

Then, a prudent and responsible decision maker should consider, in its evaluation and selection of strategies to follow, each time the reference context, differentiating his behavior from situations of certainty, risk or uncertainty. We talk about decision making under certainty when you can be sure, without doubt the authenticity of a case; in risk conditions, when you cannot be sure of the authenticity of a case but this one can be estimated with a certain probability rate; in uncertainty, when you cannot assess the authenticity of a case and cannot understand the probability that this is true, because you haven't information to make a reasonable estimate [31].

It is essential to distinguish between conditions of certainty, uncertainty or risk, because it has power over the chance to estimate probability of occurrence of an event and to determine the most appropriate and effective decision-making strategies in a specific situation. Under conditions of certainty, you will choose the action whose outcome provides the greatest usefulness; in a risky situation, you will value the greatest expected utility; in uncertain case, no decision can be considered completely reliable or reasonable and effects should be considered random [32]. In situation of uncertainty, manager doesn't know historical data suitability and future probability of occurrence, and there are infinite factors which could influence events evolution and change preliminary decision-making conditions.

Normally, in order to know the risks we are exposed, we need to choose the probability distribution form so well as to calculate the risks and find out the probability that a past event comes up again in the future. If you need a probability distribution to understand the future behavior, it's also true past events knowledge is necessary to determine the probability distribution. In other words, we are in a vicious circle [35].

One of the main problems is that risk management science has been addressed, in the last century, by an econometric and mathematical point of view, looking for potential models which were able to forecast loss distribution. What it's not clear is that risks of using a wrong probability distribution aren't obviously predictable and can be even more dangerous than those detected by chosen distribution tails [36].

The main problem of risk management is determined by the fact that general properties of the generators (distribution shape)[2] usually outline a uncertain situation and not hazardous one. The worst mistake that can make the risk manager is to confuse uncertainty with risk, failing to define class and generator parameters.[3]

A generator has specific parameters that determine certain values of the distribution, allows analysts to calculate the probability that a certain event occurred. Usually the generator isn't known and there is no independent way to determine the parameters, unless you try to deduce from the past behavior of the generator. To estimate the parameters from historical data is still necessary to assume the generator class (Normal, Poisson, Binomial and other).

These estimates are more accurate as larger is the amount of data available. Logically, an inappropriate choice of the type of generator immediately affect the reliability of results (in terms of imprecise probability of occurrence of risky events).

The risk manager can run into several situations:

- the type of generator is easily identifiable and there is an adequate supply of past data;
- the generator can be considered reliable, but the lack of historical data makes impossible to correctly determine the moments;
- you cannot determine either the parameters or the general class of membership.

The last point is usually the dominant situation in which the relationship between expected risk and actual risk is still undetermined or accidental. There is a state of uncertainty, where it cannot be sure what will happen, or make any estimates on the probability of hypothetical

[2]The term "generator" refers to the type of distribution that best estimate a well-defined set of data.

[3]See [30,33]. The distinction between risk and uncertainty is roughly that risk refers to situations where the perceived likelihoods of events of interest can be represented by probabilities measured by statistical tools using historical data, whereas uncertainty refers to situations where the information available to the decision-maker is too imprecise to be summarized by a probability measure [30,33,34].

cases.

Therefore, risk managers should not confuse uncertainty with risk, failing to define both the class generator and its parameters. A fact is making decisions under risk, where you know the distribution of a given phenomenon and the probability that a harmful event, another fact is to do it under conditions of uncertainty where the distribution is only conceivable and the probability of events is not accurately defined.

Further perspective is provided by recalling the role of differentiability in decision theory under risk, where utility functions are defined on cumulative distribution functions. Much as calculus is a powerful tool, Machina [37] has shown that differential methods are useful in decision theory under risk. Epstein [29] adds to the demonstration in Machina that differential techniques are useful also for analysis of decision-making under uncertainty.

Operational losses are usually forecasted using parametric and actuarial approaches as LDA (Loss Distribution Approach) or more cautious EVT (Extreme Value Theory) [38]. The main problems of this approaches concern the choice to reduce any event distribution to consolidated generator (normal, lognormal, GPD or other) and the need for consistent time series to obtain values appropriate risk.

The key attraction of EVT is that it offers a set of ready-made approaches to a challenging problem of quantitative operational risk analysis and try to make risks, which are both extreme and rare, appropriately modeled. Applying classical EVT to operational loss data however raises some difficult issues. The obstacles are not really due to a technical justification of EVT, but more to the nature of the data. EVT is a natural set of statistical techniques for estimating high quantiles of a loss distribution, which well works with sufficient accuracy only when the data satisfy specific conditions [39].

The innovation introduced by fractal model is the flexibility to adapt event distribution to real one without setting up the best generator. So you don't need to assume the shape of the generator because ifs allows to reproduce the structure of real distribution on different scales, exploiting the properties of self-similarity[4] of fractals.

The fractal building is based on an innovative algorithm which is iterated a theoretically infinite number of times so that, in each iteration, the approximated distribution better estimates the real one. The IFS (Iterated Functions System) technique finds out the more appropriate generator without a known model application [40]. Moreover the properties of fractals allow to estimate the event distribution in a reliable manner even if we have a lack of historical data.

Therefore the advantage of this approach is to give risk managers a tool to avoid the mistake of neglecting risks, regardless having to fix a suitable standard generator. A best estimate of an event risk level enhances the efficiency of its management, monitoring and control and reduces exposure of the organization.

5. Sample and Methodology

Our analysis is based on a two year operational loss data collection by an Italian banking group[5]. The dataset contains operational losses broken down by eight business lines and seven event types in accordance with the Basel II rules. The business lines are: Corporate Finance, Trading & Sales, Retail Banking, Commercial Banking, Payment & Settlement, Agency Services, Asset Management and Retail Brokerage. The event types are: Internal Fraud, External Fraud, Workplace Safety, Business Practice, Damage to Physical Assets, Systems Failures, Execution & Process Management.

The available data consist of a collection of operational losses of an Italian banking group for a time period of two years divided into company code, type of business line, risk drivers, event type, amount of loss, date of occurrence, frequency of occurrence.

To have a significant analysis, we had to use a time horizon of one month instead of one year for our estimations (then, we have 24 observations of the aggregate monthly loss), and to focus only on the business line (we do not care of the event type); we analyze two different business lines: the traditionally HFLI[6] retail banking [15] and the traditionally LFHI[7] retail brokerage [41].

In **Table 1** we show the descriptive statistics of retail banking and retail brokerage. In the retail banking business line we have 940 loss observations (high frequency business lines), the minimum loss is 430 euros, the maximum loss is 1066685 euros and the average loss is 13745 euros. In the retail brokerage business line we have 110 loss observations (low frequency business line) with a minimum loss of about 510 euros, maximum loss of 700000 euros and an average loss of 28918 euros (higher than retail banking business line).

We have used for our analysis three types of approaches: the traditional Loss distribution approach (LDA), the refined Extreme Value Theory (EVT) and the innovative fractal based approach Iterated function sys-

[4]The basis of self-similarity is a particular geometric transformation called dilation that allows you to enlarge or reduce a figure leaving unchanged the form.

[5]For reasons of confidentiality we cannot use the group name

[6]High Frequency Low Impact

[7]Low Frequency High Impact

Table 1. Descriptive statistics of retail banking (left) and retail brokerage (right).

	Retail Banking (940 *obs.*)	*Retail Brokerage* (110 *obs.*)
Min.	438	509.6
1^{st} *Qu.*	1302	1071.4
Median	3000	2124.3
Mean	13745	28918.3
3^{rd} *Qu.*	8763	13375.0
Max.	1066685	700000.0

tems (IFS).

First of all, we consider the actuarial-based Loss Distribution Approach. The goal of the LDA methodology consists in identifying the loss severity and frequency distributions and then calculate the aggregate loss distribution through a convolution between severity and frequency.

LDA is built upon two different distributions, estimated for every cell of the Business Line-Event Type1 matrix (ij): the distribution $FX_{ij}(x)$ of the random variable X_{ij} which represent the loss amount trigged by a single loss event. This distribution is called loss severity distribution.

The distribution $P_{ij}(n)$ of the counting random variable N_{ij}, which probability function is $p_{ij}(k) = P(N = k)$. P_{ij} is said loss frequency distribution and corresponds to:

$$P_{i,j}(n) = \sum_{k=0}^{n} P_{i,j}$$

These two distributions (which have to be independent from each other) represent the core o the LDA approach, and are used to obtain the operational loss calculated on (mainly) a one-year horizon (in our case one-month horizon) for the ij cell:

$$L_{i,j} = \sum_{n=0}^{N_{ij}} X_{i,j,n}$$

The main approach to study extreme events is the Extreme Value Theory (EVT), which is a statistical methodology that allows analysts to handle separately the tail and the body of the distribution, so that the influence of the normal losses on the estimation of the particularly high quantiles can be eliminated. This technique was developed to analyze the behavior of rare events and to prevent natural catastrophes (*i.e.*, floods or losses due to fires). There are two classes of distribution in particular which prove to be useful for modeling extreme risks: the first one is the Generalized Extreme Value (GEV) and the second one is the Generalized Pareto Distribution (GPD).

The Iterated Function Systems (IFS) represent a mathematically complex class of innovative and non-parametric fractal methods to create and generate fractal objects as an approach to shift between time towards space [40]. The fractals are geometric figures that can be represented at different dimensional levels, but they consist in an infinite replica of the same pattern on a smaller and smaller scale and so they are made up of multiple copies of themselves. This fundamental property of invariance is called self-similarity, one of the two principal properties that describe a fractal. The second property, not less important, is the indefiniteness, which is the possibility to fractionate virtually till infinite every part before going to the next one. Hence, to "draw" a fractal through a processor, the maximum number of iterations must be specified, because a finite time is insufficient to calculate a point of the fractal at infinite iterations.

One of the IFS possible fields of application is risk management, in which fractal methods are used as non-parametric estimation methods as an alternative to the Loss Distribution Approach (LDA) and the EVT [39]. These innovative methods can both interpret the data of loss in a more accurate way, and estimate and recreate the possible population from which they could derive, especially when there are few observations or data. The advantage of this approach is that the elaboration processes can be reduced while improving, at the same time, the capacity of estimation of the patrimonial requirements necessary to cover the expected and unexpected operational losses[8]. IFS methods eliminate the necessity to analyze the distribution of frequency[9], of severity[10] and of the correlated convolutions between them, simulating directly the cumulative distribution of the aggregate losses and then applying the most efficient measure of risk[11]. Consequently, they become a fundamental element in the analysis of losses, especially in correlation with the so called extreme losses, which are the losses that, due to their very low probability of occurrence, tend to be ignored, although their occurrence could determine catastrophic consequences.

In the next section, the fractal approach will be applied

[8]The expected loss is defined as the mean of the losses observed in the previous periods. The unexpected loss is defined as the difference between the VaR and the expected loss and, resulting more difficult to be represented in a model, represent for the business management an element of uncertainty which can be minimized only through ad adequate estimation.

[9]For distribution of *frequency* we intend the frequency of the occurrence of the events.

[10]For distribution of *severity* we intend the financial impacts generated by the losses.

[11]In our case Value at Risk

to a specific case with the intent to demonstrate, at a practical level, what kind of information can emerge from the use of this approach and how this information can be used to improve the business management.

6. Estimation by IFS Approach

The non-parametric estimation we offered as an alternative way to LDA methodology and the Extreme Value Theory is the IFS fractal based approach which should be able to interpret loss data in the best possible way and to simulate a population (see **Figure 2**) from which our observations could come and especially in the presence of a few observations and missing data (as in the case of retail brokerage). The advantage of this approach is to eliminate the analysis on frequency and severity distribution with related convolution and the previous choice of a known distribution to directly simulate the cumulative distribution function of the aggregate operational losses and then apply a risk measure to calculate capital requirements to cover operational losses in the business lines we studied.

The Iterated Function Systems, designed originally from Barnsley for the digital image transfer [42], depth by Forte and Vrscay [43] for solving inverse problems, and used by Iacus and La Torre for their estimation and simulation mathematical property of probability functions [40] and, finally, adapted to the capital requirements calculation of operational risk, have shown over other methods (such as LDA and EVT) more relative efficiency in terms of ability to reconstruct a population of losses.

We used the function *arctang* for transforming the values of loss in values between 0 and 1 to allow the IFS approach, that functions on a finite support (in our case precisely between 0 and 1), to estimate the operational cumulative distribution function starting from the empirical distribution function (EDF).

First, we have to demonstrate that IFS approach is better than LDA and EVT to reconstruct a population from

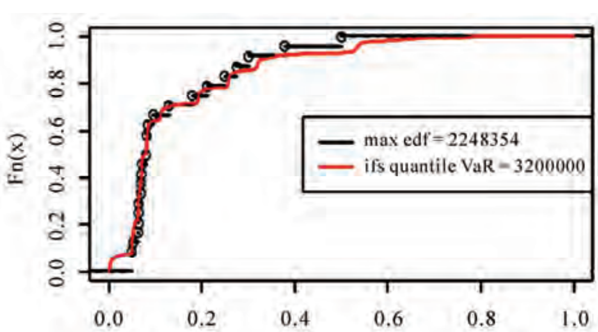

Figure 2. Example of IFS simulation in retail banking.

which our information could come and especially in the presence of few data. The methodology to demonstrate the capability of the IFS estimator to reconstruct the original population is to calculate a statistical distance from the original distribution of the IFS simulation and comparing the results obtained with the classic method used in the actuarial science (LDA) and the most innovative method of Extreme Value Theory. For our analysis we use observations of operational losses caused by fires. The database Danish Fire Losses in literature has been used to test both classical techniques such as LDA that EVT as the newest techniques and lends itself very well to the study of extreme and complex events as demonstrated by McNeil *et al.* al. [44] and therefore it represents a good test for analyzing and evaluating the relative efficiency of the fractal approach versus parametric techniques such as LDA and EVT. This database contains daily observations of loss arising fire in Denmark in millions of Danish crowns from January 1980 to 1990 and is free downloadable in the package QRMLib by R 2.10.0 project. We proceed extracting random samples of different sizes from the database and then simulate the real distribution of losses through the use of IFS maps for small sample size (n = 10, 20, 30) and medium sample (n = 50, 100, 250). Finally we compare the results obtained by IFS approach in terms of AMSE[12] distance with the results obtained by LDA and EVT approaches.

In **Table 2** we show the behavior of the AMSE index[13] (calculated over 100 simulations for each sample size).

The indices show us how IFS approach is more efficient for small sample size than LDA and EVT, while for samples of medium and large size we find an asymptotic behavior between LDA approach and IFS one.

Secondly, we apply this new fractal methodology for estimating enterprise capital requirements that a firm must allocate to cover operational risks. We know the main problem for the operational risk analysis is the lack of information and the lack of data, so we use the power and the capability of the fractal objects to reconstruct a population starting from this lack of information to better understand the real risk profile of the firm and to improve the decision making process inside the company. In **Table 3** we show the result of non-parametric estimation made by IFS approach for the retail banking and retail brokerage business lines compared with the value obtained by LDA VaR, EVT VaR and the maximum value of the empirical distribution function.

In the two business lines in which we were able to apply all the three approaches proposed in this paper, we

[12]Average mean square error
[13]Lower is the value of the AMSE index better is IFS approach versus LDA and EVT

Table 2. Relative efficiency of IFS estimator over LDA and EVT.

n	*AMSE over LDA*	*AMSE over EVT*
10	65.13	24.05
20	73.52	31.26
30	75.15	25.95
50	79.33	22.27
100	111.12	21.05
250	115.67	21.11

Table 3. Value at Risk by different approaches.

Business line	*LDA VaR*	*EVT VaR*	*IFS VaR*	*Max EDF*
Retail banking	1531369	4420998	3200000	2248354
Retail brokerage	1061966	4929569	1451000	931607

obtained, with IFS method, estimates in the middle between the Extreme Value Theory which tends to overestimate widely the capital requirements and the Loss Distribution Approach which tends to underestimate the requirements (for example in the case of retail banking). Another IFS advantage is the ease of use, meaning that you do not need to simulate a distribution for the severity and for the frequency and the related convolution, but is enough to measure directly the aggregated operational loss distribution (monthly in our case given the number of observations available) and apply to this distribution a measure of risk.

The strength of this fractal approach has demonstrated its ability to capture the true risk profile of a company even with lack of data.

Of course not everything is positive, but we must take into account and know perfectly well there are inherent disadvantages and limitations that make each model less accurate and sensitive to errors. Firstly like all nonparametric approaches, the IFS are very sensitive to the sample data used. Several samples extracted from the same population can lead to estimates and simulations widely different between them. It is a good idea to use a very large number of simulations in order to obtain consistent estimates.

7. Conclusions

In recent years, there has been increasing concern among researchers, practitioners, and regulators over how to evaluate models of operational risk.

The actuarial methods (LDA) and the Extreme Value Theory (EVT) constitute a basis of great value to fully understand the nature and the mathematical-statistical properties of the process underlying the operational losses, as regards the severity of losses, the frequency of losses and the relationship between them.

Several authors have commented that only by having thousands of observations can interval forecasts be assessed and traditional techniques need a large amount of data to be precise and effective. However, currently available data are still limited and traditional methodologies fail to grasp the correct risk profile of firms and financial institutions, as shown the empirical analysis undertaken in this article. With IFS technique you can estimate appropriate risk value even if you have just few data. Increasing data availability, IFS outcomes tend to be as suitable as traditional methods.

So, we can say that the study, the analysis and the improvement of innovative methods such as Iterated function systems (IFS) is a valuable support for measurement and management the operational risk alongside actuarial parametric techniques. Not only that, their use is not limited only in the next years, pending more complete series. Their use should include those areas of operational risk, which is by definition heterogeneous and complex, have a limited numbers of events, but their impacts can, however, be devastating for firms and stakeholders. Precisely for this reason the use and improvement of these innovative tools must continue for the foreseeable future because there will always be the need in this area of innovative approaches able to predict, with good approximation, situations starting from this lack of data and reconstruct a precise and faithful population to integrate and assess the results of other different approaches.

As such as every mathematical method, IFS could help risk management making quicker knowledge learning process but what is really important is a careful and prudent management behavior.

Thus we can conclude, firstly, mathematical approaches are effective only when they are integrated and shared in a responsible corporate culture. Secondly, IFS as a nonparametric method is sensitive to the composition of used sample; for an appropriate estimation of operational loss with IFS you should reapply the methods more times and then estimate an adequate average level. More cautiously you apply mathematical techniques, more probable is a accurate estimation of hedging value of the total operational risk. Finally, being the first time IFS is applied to operational risk, future improvements are probable.

In our intentions is we would extend the application of this methods to financial and credit risk. However this goal needs we are able to use IFS to estimate not just probability function but density one. The main problem it requires to apply a Fast Fourier Transform, as shown by Iacus and La Torre [40].

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J. Service Science & Management, 2010, 3, 363-368
doi:10.4236/jssm.2010.33042 Published Online September 2010 (http://www.SciRP.org/journal/jssm)

Decision-Making Optimization of TMT: A Simulated Annealing Algorithm Analysis

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Received May 14th, 2010; revised June 19th, 2010; accepted July 26th, 2010.

ABSTRACT

The decision-making of Top management team (TMT) has been a hot point in academic. The paper find out annealing algorithm method can effectively solve the decision-making optimization problem. Through considering the quality and efficiency of decision-making, applying the annealing algorithm, the optimal decision preference sequence is found. Finally, an application case is proposed. Through determining the initial solution, and choosing the solution neighborhood, and setting the cooling function and temperature, with the simulated annealing algorithm, the optimal solution of the decision is achieved.

Keywords*: *Top Management Team, Simulated Annealing Algorithm, Decision-Making

1. Introduction

Upper Echelons Theory is the theory which has profound impact in the academic circles. It is proposed in 1984 by Hambrick and Mason who suggested that researching into top management team (TMT) decision-making instead of individual decision-making would decrease the decision fault caused by the individual of limited rationality [1]. As a result, problems about decision-making of TMT become popular and stimulate a lot of research. Most part of the research has focused on TMT demographic characteristics and their heterogeneity. The researchers suggested that the demographic characteristics and their heterogeneity could reflect the decision-making of TMT and predict organization outcome. There is advantages in this static analysis which can evaluate and predict performance of a company to some degree, however, the demographic characteristics are not the exact reflection of TMT decision-making [2], and cannot answer the question of decision-making optimization of TMT. In this case, we propose two dimension which is decision efficiency and decision quality to analyze decision-making optimization of TMT and find out the optimal decision preference sequence.

2. Literature Review

In the violent changing society, decision effect is directly influenced by decision efficiency. Ensley (2000) suggested that decision efficiency and cohesion are two core factors influencing team performance [3]. In fact, team cohesion is a kind of condition and display of decision-making quality. To improve the decision-making quality is one of the key factors which prompt the top management research changing from individual level to team level. Decision-making quality of TMT has important influence on decision-making effect despite of the changing environment. Therefore, the decision-making effect depends on decision-making efficiency and decision-making quality. Higher level of decision-making efficiency and decision-making quality will result in better decision-making effect.

2.1. Measurement of Decision-Making Efficiency

How can we achieve high decision-making performance? Economist Heyek once pointed out that decision-making efficiency depended on the matching degree of decision-making power and key decision knowledge [4]. He suggested to combine the power and the knowledge. Only combining the two can it achieve high efficient decision-making. However, Heyek's saying is too obscure that he didn't point out how power and knowledge combined. In fact, decision-making efficiency can be measured by the weighted preference of all the alternative choices from all decision-makers, that is to say, base on the consideration of all decision-makers' decision-making preference, comprehensively consider the "preference distance" be tween the final and the original preference sequence of decision-making which is the difference of the two. If the "preference distance" between the two is bigger, the efficiency will be lower.

2.2. Decision-Making Quality

To improve decision-making quality of individual executives is the primary idea of introducing the theory of TMT [1]. Although the substitution of group rationality for individual rationality can't completely eliminate the negative influence of limited rationality in improving decision quality, it can validly reduce the bounded rationality in decision-making which comes from the interactions between team members [5]. However, interaction is only the necessary condition in improving decision-making not the sufficient condition, so the decision quality evaluation should be done by other factors. Reviewing the related past research on quality of decision-making, the decision-making quality evaluation is mainly done by the subject idea of the TMT members which mainly using psychological scale to investigate TMT's opinion to every decision-making quality, such as Wang Guofeng (2007) [6]. The inner logic lies in the feasibility of decision-making quality evaluated by satisfaction degree of TMT. This rooted in the posterior characteristic which TMT decision-making quality should be evaluated by the objective decision implementing effect, however, in the real setting, it is not feasible. One reason is that it will take quite a long time to see the actual effect, when the time past, the uncontrollable factors influenced decision will increase. So, the ineffective of decision can not attribute to the bad quality of decision-making; another reason is that it won't be good for the improving of decision process if the decision-making factor be evaluated by the decision implementing effect. Therefore, this paper uses the satisfaction of top management team with the decision-making process to evaluate the decision-making quality. When the degree of TMT members' satisfaction in decision-making with the decision-making quality is higher, the decision-making quality is higher.

3. Optimization Model of TMT Cognitive Integration

Based on above findings, the optimization model of top management team cognition integration is built. Suppose in every decision process, TMT faces a decision-making program set, set it as A={a_j}, j=1, 2, …, n, TMT members set K={k_i}, i=1, 2, …, m. First, TMT members form preference sequence of the program set A based on their own information sources, set the sequence as X={x_{ij}}. The principles of optimization of cognitive integration are high decision making efficiency and high quality.

3.1. High Efficiency of Decision-Making

Based on the consideration of the weight of every decision-maker, when the "preference distance" between final and original preference sequence of TMT decision-making is smaller, the efficiency of decision-making will be higher. For the "preference distance" measurement, some scholars (such as Zhang Lin *et al*, 2004) proposed to use the Mahalanobis distance [7]. However, in fact, compared to the Euclidean distance, Mahalanobis distance gets its advantages in the correlated sample. In this study, the primary preference based on their own discretion rather than on the idea of intercommunication. It depends more on the inter independence rather than the inter correlation. So, it is more easy and effective to use Euclidean distance than Mahalanobis distance. As it is known that Euclidean distance $d_E(x,y)$ between two point (or vectors) x, y is:

$$d_E(x,y) = \sqrt{\sum (x-y)^2} \tag{1}$$

To simplify the calculations, the "preference distance" will take the square of Euclidean distance, which is "preference distance" d_i:

$$d_i = \sum_{j=1}^{n} (x_{ij} - e_j)^2 \tag{2}$$

The shorter of Euclidean distance means the higher of decision-making efficiency. Considering different weights W_i of each decision-maker in decision-making, the following model can be established to represent the decision-making efficiency optimization:

$$\begin{cases} \min E(x) = \sum\limits_{i=1}^{m} w_i d_i = \sum\limits_{i=1}^{m} w_i \sum\limits_{j=1}^{n} (x_{ij} - e_j)^2 \\ s.t. \sum\limits_{i=1}^{m} w_i = 1, 0 < e_j < 1, 0 < x_{ij} < 1, w_i > 0 \end{cases} \tag{3}$$

3.2. High Quality of Decision-Making

The quality of decision-making can be measured by TMT members' satisfaction degree with the decision quality. Zhang Lin *et al* [7] proposed the concept of using relative entropy to measure the quality satisfaction with decision-making. The so-called relative entropy is an important concept in information theory which measures the fitness degree of two messages. As to variable X, Y, when $X=(x_1, \ldots\ldots x_n)$; $Y=(y_1, \ldots\ldots y_n)$, $0 \le x_n \le 1$, $0 \le y_n \le 1$, and $\sum_{i=1}^{n} x_i = \sum_{i=1}^{n} y_i = 1$, the relative entropy of X compared to Y is $h(x,y) = \sum_{i=1}^{n} x_i \ln \frac{x_i}{y_i} \ge 0$. Obviously, $\forall i$, if and only if $x_i = y_i$, $h(x,y)$ get its minimum. In reverse, the lower of $h(x,y)$, the more closer between

x_i and y_i, So $h(x,y)$ can be use to measure the fitness degree between x_i and y_i.

When the fitness between final optimal solution sets decided by TMT after discussion and the preference sequence of every TMT is higher, the overall satisfaction is higher thus with the decision-making higher as well. So the decision-making quality of TMT can be measured by q_i:

$$q_i = \sum_{j=1}^{n} x_{ij} \ln \frac{x_{ij}}{e_j} \tag{4}$$

Considering different weight W_i of every TMT member in decision-making, a model can be established to simulate the optimization of decision-making quality:

$$\begin{cases} \min Q(x) = \sum_{i=1}^{m} w_i q_i = \sum_{i=1}^{m} w_i \sum_{j=1}^{n} x_{ij} \ln \frac{x_{ij}}{e_j} \\ s.t. \sum_{i=1}^{m} w_i = 1, 0 < e_j < 1, 0 < x_{ij} < 1, w_i > 0 \end{cases} \tag{5}$$

Integration of the various members of TMT preference was based on the consideration of both decision-making quality and decision-making efficiency, that is either to find the fittest preference set to ensure the decision-making efficiency or make every TMT member satisfy to ensure the decision-making satisfaction. So, the optimization model of TMT decision-making process can be express by following equation set:

$$\begin{cases} \min decision = \alpha E\left(e_j\right) + \beta Q\left(e_j\right) \\ \qquad = \sum_{i=1}^{m} w_i \left(\alpha \sum_{j=1}^{n} (x_{ij} - e_j)^2 + \beta \sum_{j=1}^{n} x_{ij} \ln \frac{x_{ij}}{e_j} \right) \\ s.t.\ \alpha + \beta = 1, \alpha > 0, \beta > 0, \\ \qquad 0 < e_j < 1, 0 < x_{ij} < 1, \\ \qquad \sum_{i=1}^{m} w_i = 1, w_i > 0 \end{cases} \tag{6}$$

In equation (6), $decision$ is the dependent variable of object function, α, β are the weight factors of decision-making efficiency and decision-making quality, represent the importance of efficiency and quality of TMT decision-making. When the value of α is bigger representing that TMT laid more emphasis on decision-making efficiency; when the value of β is bigger representing that TMT laid more emphasis on decision-making quality. The object of TMT cognition integration optimization is to find out the optimize preference sequence set $E(e_j)$. As can be seen from the equation set, this problem is a NP-hard problem, and is a kind of continue optimization problem which is hard to get overall optimal solution by ordinary methods. Even if the optimal solution can be achieved, the solution efficiency is low enough. So, we use the Simulated Annealing (SA) Algorithm to solve the problem.

4. Problem Solving

Simulated annealing algorithm (Simulated Annealing Algorithm, SA algorithm) is inspired by the phenomenon of annealing process in thermodynamics which will achieve equilibrium ultimately. SA can search for the optimal solution simulating the annealing process. The algorithm can achieve an approximate global optimal solution in polynomial time through the selection of relatively small state in target areas in certain probability [8]. In this paper, the reason to use SA is as follows.

(1) SA likewise intelligent optimization algorithms is "problem dependent", and its research focus is on the application of algorithm in various complex problems [8]. However, in the research of TMT, seldom application researches of SA can be seen.

(2) Compared to genetic algorithms and other intelligent optimization algorithm, SA is more effective in finding the global optimal solution as it accept second-best solution in certain probability through the rules of Metropolis which greatly enhance the capacity of global searching.

The solving step of this problem can follow several steps:

Step 1: Each TMT member has their own preference to the program set, to put them all we can get the initial preference sequence of TMT , randomly choose an initial solution $E^i=\{e_1^i,\ldots\ldots, e_n^i\}, 0 \le e_l^i \le 1$, $l=1,2,\ldots,n$. Given initial temperature T_0 and ending temperature T_f, let iteration index $k=0$, $T_k = T_0$.

Step 2: In the neighborhood of initial solution, randomly generate a neighbor solution $E^j=\{e_1^j,\ldots\ldots,e_n^j\}$, $0 \le e_l^j \le 1$, $l=1,2\ldots,n$, calculate the incremental value of the objective function:

$$\Delta decision = decision(e_l^j) - decision(e_l^i) \tag{7}$$

Step 3: If $\Delta decision < 0$, let $i=j$ and go to step 4; otherwise, generate $\xi = U(0,1)$, if $\exp\left(-\frac{\Delta decision}{T_k}\right) > \xi$, let $E^i=E^j$.

Step 4: If the thermal equilibrium (*i.e.* frequency of inner cycle become greater than the frequency of setting cycle $n(T_k)$), then go to step 5; otherwise go to step 2.

Step 5: According to $T_{k+1}=r \cdot T_k$ lower the temperature, (r generally values from 0.95 to 0.99 with two decimal places, otherwise the cooling rate either too fast or too slow), $k=k+1$, if $T_k < T_f$ the algorithm stops, otherwise go to step 2.

5. Application Examples

A TMT of one firm with five members which one is CEO while the others are vice presidents in charge of each functional department. In one decision-making conference, there are 6 decision programs for discussion and decision. Before the decision debate, the preference sequences to the decision program of every TMT member are listed as **Table 1**.

Suppose the decision weight of CEO is 0.4, each vice president is 0.15, the weight factor α, β of decision-making quality and decision-making efficiency are both 0.5. That is, the decision-making quality and efficiency are the same important.

5.1. According to the Problem Characteristics to Determine the Initial Solution

If randomly generate an initial solution, high temperature annealing process would be relatively long. CEO noted that the weight is high, the initial solution can be shilling for the CEO's preference sequence, that is, $\mathbf{E}^0$ = (0.5, 0.4, 0.8, 0.3, 0.1, 0.3). Considering the decision weight of CEO is the highest, we can choose the CEO's preference sequence as initial solution, that is, E^0 = (0.5, 0.4, 0.8, 0.3, 0.1, 0.3).

5.2. The Choice of Neighborhood

The choice of neighborhood plays a very important role in problem solving efficiency, but the choice methods closely linked to specific issue. Because the solution of this problem is in the (0, 1) interval, and the computer will treat the solution closed to 0 as 0 as limited by the computer precision, the program running would occur error as the calculation has exceeded the definition domain. So, it is not suitable to have a random search around the neighborhood of the previous solution. In order to ensure not only the solution is in the definition domain, but also ensure a relatively wide search range, we carried out the following neighborhood search method as follows to determine the new solutions: First, code the preference sequences exactly from the original sequence, such as (0.5, 0.4, 0.8, 0.3, 0.1, 0.3), then swap the preference value in the sequence itself. As the size of neighborhood is c_6^2 =15, so the number of inner loop is 15 times.

Table 1. Initial decision preference order of TMT.

TMT \ program	1	2	3	4	5	6
CEO	0.5	0.4	0.8	0.3	0.1	0.3
VP1	0.4	0.5	0.7	0.8	0.2	0.5
VP2	0.7	0.2	0.3	0.7	0.2	0.4
VP3	0.6	0.7	0.2	0.6	0.4	0.5
VP4	0.6	0.6	0.1	0.5	0.8	0.1

5.3. The Choice of Cooling Function

There are many setting of cooling function. According to the characteristics of this problem, we use moderate cooling rate, the cooling function is defined as $T_{k+1}=r\cdot T_k$, r equals 0.97, that is $T_{k+1}=0.97\cdot T_k$.

5.4. The Initial Temperature and the to be Determined Temperature

According to the scale of this problem, the initial temperature T_0 equals 50, final temperature T_f equals 0.1.

5.5. The Retention of Good Solution

Although in theory, the probability of a simulated annealing algorithm will converge to global optimal solution at a probability of 1, but it is far from the reality [9], it is greatly related to the actual problem solving. In this study, as neighborhood search is random exchange within the old solution, the search process is random, so the global optimal solution may appear in the iterative process but the end. As a result, in order to prevent missing out the optimal solution, all solutions must be retained per iteration, and then filter them where the optimal solution can be determined.

5.6. Result

According to the above algorithm and parameter setting step, using VB language for programming, after 20 times iteration, removing repetitive solution, obtain the following results shown in **Table 2**:

As the minimum function value is 0.0942 is, so respectively (0.4, 0.5, 0.3, 0.3, 0.8, 0.1) is the optimal TMT decision-making preference sequence, and thus program 5 with the weight 0.8 is the optimal program. This is the solution under 20 iterations calculation. According to SA algorithm, this solution is the global optimal solution of this problem.

Obviously, optimal solution (0.4, 0.5, 0.3, 0.3, 0.8, 0.1) is quit different from the mean value of preference sequence (0.56, 0.48, 0.42, 0.58, 0.34, 0.36) which represent that it would not achieve high efficient and high quality decision-making through simple averaging. This may attribute to the mean value which represents a "compromise" program, and this simple "compromise" approach may put the choice of the program into two problem: on one hand, it can not take into account the interests and preferences of all decision-maker which a simple "compromise" program can not be accepted by everyone very quickly; on the other hand, the "compromise" preference program is different from most member's preference which more or less make TMT members

Table 2. Calculation result.

Program / Iteration	1	2	3	4	5	6	Function value
1	0.8	0.3	0.1	0.3	0.5	0.4	0.1666
2	0.4	0.5	0.3	0.3	0.8	0.1	0.0942*
3	0.3	0.4	0.1	0.3	0.8	0.5	0.1626
4	0.1	0.4	0.3	0.3	0.5	0.8	0.3661
5	0.8	0.4	0.3	0.5	0.1	0.3	0.3299
6	0.8	0.1	0.3	0.3	0.5	0.4	0.279
7	0.3	0.3	0.1	0.8	0.5	0.4	0.1481
8	0.5	0.3	0.4	0.3	0.8	0.1	0.1308
9	0.4	0.8	0.1	0.3	0.3	0.5	0.222
10	0.3	0.3	0.1	0.5	0.8	0.4	0.1481
11	0.4	0.1	0.3	0.5	0.3	0.8	0.4071
12	0.3	0.5	0.1	0.8	0.4	0.3	0.174
13	0.1	0.8	0.3	0.5	0.4	0.3	0.2703
14	0.3	0.4	0.1	0.5	0.8	0.3	0.1131
15	0.3	0.1	0.4	0.3	0.5	0.8	0.4027
16	0.5	0.3	0.1	0.4	0.8	0.3	0.1068
17	0.3	0.3	0.1	0.4	0.8	0.5	0.1699
18	0.5	0.3	0.1	0.3	0.4	0.6	0.2664
19	0.3	0.1	0.3	0.4	0.8	0.5	0.2823
20	0.8	0.5	0.4	0.3	0.3	0.1	0.1902

unsatisfied which result in overall deny of this program. Therefore, a simple compromise decisions is inappropriate. It should take into account the preferences of all decision-makers with in-depth exchanges and discussions and the consideration of decision-making efficiency and all parties' satisfaction, thus comes out the optimal decision.

6. Conclusion and Discussion

This study found that:

First, taking into account both the quality of decision-making and efficiency of decision-making, the TMT, the average decision-making preference sequence is not the optimal sequence. TMT decision-making therefore can not simply choose the mean preferences of all team members. When choosing decision-making program with "mean highest" method should also taken the quality and efficiency of decision-making factors into account, using more advanced algorithms such as simulated annealing algorithm to find out the optimal decision sequence.

Second, simulated annealing algorithm can successfully solve the optimization problem of TMT decision-making, and it is an effective tool in complex issues in TMT decision-making optimization.

The shortcomings of this study are:

First, this study only intercept two variable —the quality and efficiency of decision-making— to search for the optimal sequence of cognitive preferences, we need further investigation to find out whether there are better variables. At the same time, the usage of Euclidean distance and relative entropy to measure these two variables has not been empirical investigated but only two hypotheses based on theoretical derivations.

Second, this study did not take limited rationality into account. In fact, although the group is relatively rational than individual, it is difficult to avoid the rational bias, especially when group thinking exist [10]. Although the satisfaction degree of team member is high, the quality of the overall decision-making from external perspective may not so high. How to reduce the group's limited rationality and to improve group performance is worth studying.

Third, the application of simulated annealing algorithm will be quite different as the problem changed. So the application techniques play an important role. In this study, the using of inter-switch method in neighborhood searching greatly improve the calculation efficiency but discretize the search of new solution which makes some potential solutions cannot be searched which eliminate the advantage of stimulate annealing algorithm. This problem still needs to further investigate to find out better neighborhood search method.

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J. Service Science & Management, **2010, 3, 369-372**
doi:10.4236/jssm.2010.33043 Published Online September 2010 (http://www.SciRP.org/journal/jssm)

Study on Comprehensive Evaluation Model of Commercial Housing Price-Rationalization

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Received July 7th, 2010; revised August 10th, 2010; accepted September 12th, 2010.

ABSTRACT

In recent years, the prices of city commercial housing are soaring, causing wide attention of public and fierce discussion about whether it is reasonable for the housing prices in China. This paper attempts to establish a method to measure housing price-rationalization. Firstly, the paper establishes rationalization evaluation system of housing price from commercial housing price formation, residents' endurance and coordination parity system. Then it selects an appropriate standard ways to build affordable housing product evaluation criteria.

Keywords**:** *Commercial Housing, Rationalization of Price, Comprehensive Evaluation*

1. Introduction

Housing Industry is an important industry to promote economy and social development. In recent years, the price of commercial housing is soaring. Currently, there is a fierce controversy about whether the commercial housing prices are rational. Therefore, this paper attempts to establish a measurement system to determine the rationality of housing price.

Most rational studies about commercial housing mainly focus on two aspects: Firstly, according to bubble of the real estate, we can judge whether the commercial housing price is reasonable. Secondly, by choosing single or multiple indexes, we can study rationality of commercial housing price. Recently, the study about an index system mainly centers on analysis of single or many indexes. In a multiple criteria system, some indexes are chose to measure the rationality. There are two kinds: one results from formation of housing price, establishment, bearing capability of residents, revenue and so on[1]; another results from aspects of demand and requirement, factors of influencing price, and demand and requirement [2,3].

This paper is based on generalizing two kind of index evaluation method to establish an integrated evaluation model.

2. Index System and Determine the Weight-AHP

AHP (Analytical Hierarchy Process) is proposed by American operations researcher Satty. T. L in 1970s. AHP basic steps are as follows:

2.1. Construction of Analytic Hierarchy

Firstly, we should decompose the complex problem into single element. These elements should be divided into several groups to form different levels according to the relationship between these elements. At the top level there is usually only one element, which is the general target of the problem or the desired results. The middle layer is always the criteria layer, and the lowest layer includes the decision-making program. The dominant relationship between the elements in different levels is not necessarily complete.

According to the relevant information and practical experience, author has selected some representative and comprehensive indexes which can reflect each side of the system, to finalize the evaluation index system of the commercial housing price rationality.

1) Target layer A

The overall objective is whether the commercial housing price is rational.

2) Criteria layer B

Criteria layer includes three parts: the formation of housing price, the affordability of residents and coordination of parity price.

3) Index layer

It includes: Ratio of commercial housing, Homeownership rate, Housing Vacancy Rate, Ratio of housing

Price to Income, Housing expenditure ratio, Ratio of housing price growth rate to it of income, Ratio of rent to housing price, Ratio of housing price growth rate to it of retail price, Ratio of housing price growth rate to it of GDP. (**Figure 1**)

The ideal range of the indexes is shown in **Table 1**.

2.2. Structure the Judgment Matrix

After the establishment of the hierarchy, the relationships of the elements between the upper and lower layers were determined. In this step, decision-makers should repeatedly answer: For the guidelines B_k, which element is more important between C_i and C_j, and gives this a certain mark. The formula for assignment can be directly given by the decision-makers, or by analysis through some kind of received advice. Generally, the expert familiar with the matter can give the weight according to the 1-9 scaling law. (**Table 2**)

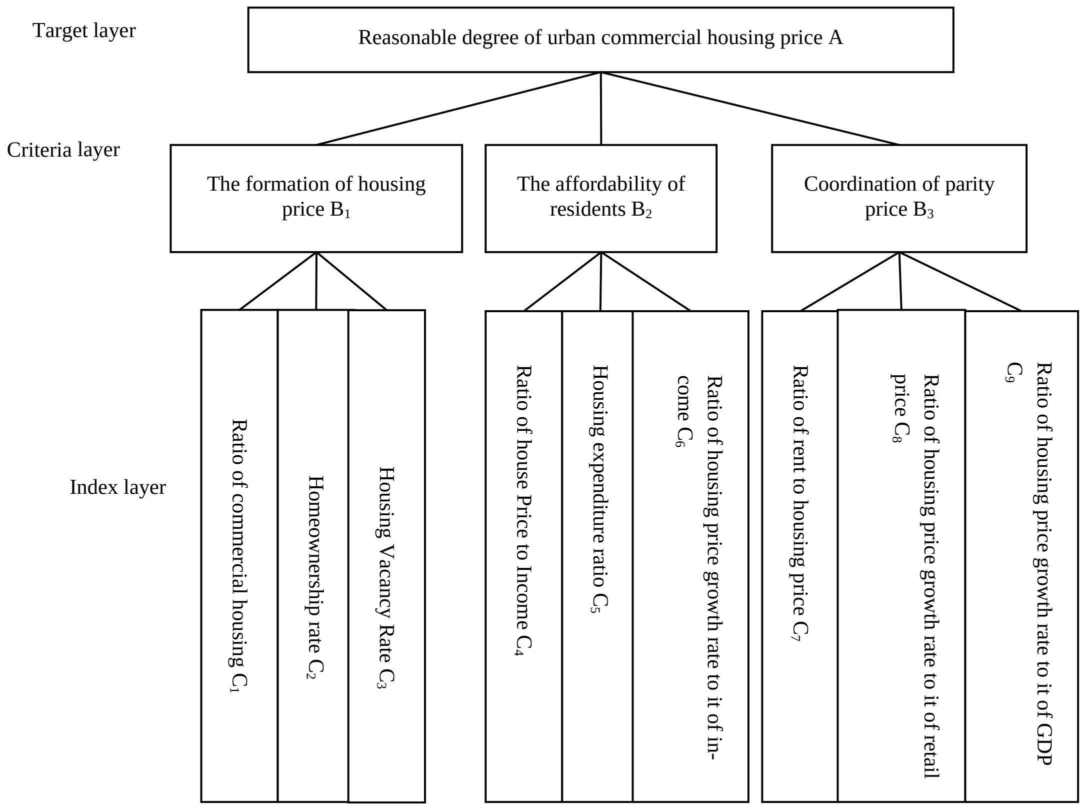

Figure 1. Rationality index system of chinese urban commodity housing.

Table 1. The ideal and rational ranges of the indexes in Figure 1.

Index	Ideal range	Max	Min
Ratio of commercial housing	90%～100%	100%	45%
Homeownership rate	60%～70%	100%	30%
Housing Vacancy Rate	15%～30%	45%	7.5%
Ratio of house Price to Income	4～7	10.5	2
Housing expenditure ratio	20%～30%	10%	45%
Ratio of housing price growth rate to it of income	0～1.2	1.8	0
Ratio of rent to housing price	100～200	50	300
Ratio of housing price growth rate to it of retail price	1.2～1.5	2.25	0.6
Ratio of housing price growth rate to it of GDP	0～1.3	2	0

Table 2. 1-9 scaling law.

Significance level	C_{ij}
Concern the previous layer, C_i and C_j are equally important	1
Concern the previous layer, C_i is slightly important than C_j	3
Concern the previous layer, C_i is obviously important than C_j	5
Concern the previous layer, C_i is strongly important than C_j	7
Concern the previous layer, C_i is extremely important than C_j	9
Concern the previous layer, C_i is slightly less important than C_j	1/3
Concern the previous layer, C_i is obviously less important than C_j	1/5
Concern the previous layer, C_i is strongly less important than C_j	1/7
Concern the previous layer, C_i is extremely less important than C_j	1/9
The important scale between the two adjacent judgments	2,4,6,8,1/2,1/4,1/6,1/8

Structure the comparison matrix $C_{n\times n}$:

$$C_{n\times n} = \begin{pmatrix} C_{11} & C_{12} & \cdots\cdots & C_{1n} \\ C_{21} & C_{22} & \cdots\cdots & C_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ C_{n1} & C_{n2} & \cdots\cdots & C_{nn} \end{pmatrix}$$

2.3. Single-Level Sorting and Consistency Check

In theory, single-level sorting can come down to the calculation of the characteristic roots and eigenvector of the judgment matrix C. $CW=\lambda_{\max}W$, here, $\lambda_{\max}$ is the maximum characteristic root, and W is the corresponding normalized vector to $\lambda_{\max}$. W_i is the component of W, it is the weight.

We choose square-root method to calculate $\lambda_{\max}$ and W. Steps are as follows:

1) Calculate M_i, the product of each row elements of matrix;

$$M_i = \prod_{j=1}^{n} c_{ij}, \quad i = 1,2,\cdots,n$$

2) Calculate $\overline{W}_i$, the n-th root of M_i;

$$\overline{W}_i = \sqrt[n]{M_i}$$

3) Normalization of the vector $\overline{W} = \left[\overline{W}_1, \overline{W}_2, \cdots, \overline{W}_n\right]^T$;

$$\overline{W_i} = \frac{\overline{W}_i}{\sum_{j=1}^{n} \overline{W}_j}$$

Then $W = \left[W_1, W_2, \cdots, W_n\right]^T$

4) Calculate the maximum characteristic root $\lambda_{\max}$;

$$\lambda_{\max} = \sum_{i=1}^{n} \frac{(AW)_i}{nW_i},$$

here, $(AW)_i$ is the i-th component of AW.

Then we calculate the consistency index $CI = \frac{\lambda_{\max} - n}{n-1}$. Obviously, when the matrix is of full consistency, CI=0. And we also need to determine the average and random index of the matrix, RI. For 1 × 1 to 10 × 10 matrix, RI is shown in **Table 3**.

When $n > 2$, the rate of CI to RI is called random consistency rate of judgment matrix (CR), CR=CI/RI.

When $CR < 0.1$, the matrix is acceptable and has full consistency. Or, proper modification is essential.

3. Weighted Comprehensive Evaluation

The linear weighted comprehensive evaluation can be more comprehensive to evaluate the rationality of urban housing price, and can identify the priorities and weaknesses. In addition, it gives a composite index which can reflect the general information. This can make up the deficiency of statistical indicator system.

Weighted comprehensive evaluation uses the individual index standardized to multiply the corresponding weight and then add to the overall evaluation.

$$A = \sum_{i=1}^{n} W_i A_i \times 100\%$$

Here, $\sum_{i=1}^{n} W_i = 1$, A: the rationality index of housing price, W_i: the weight of i-index, A_i: the rationality index of i-index.

Accordingly, $A \in [0,1]$. If A = 100%, the commercial housing prices are entirely reasonable; If A = 0, the housing prices are completely unreasonable. In this article, we provides A = 60% as the critical point, that means urban commercial housing prices is basically rational in China.

Table 3. Average random consistency index *RI*.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.26	1.36	1.41	1.46	1.49

4. Conclusions

This paper establishes the integrated evaluation model of urban commercial housing. The sorting of indexes are as follows: Ratio of commercial housing, Homeownership rate, Housing Vacancy Rate, Ratio of house Price to Income, Housing expenditure ratio, Ratio of housing price growth rate to it of income, Ratio of rent to housing price, Ratio of housing price growth rate to it of retail price, Ratio of housing price growth rate to it of GDP. On one hand, the results reflected the relative importance of the factors which affect China's commercial housing. On the other hand, it reflects we should cut down housing prices, increase income, and improve the affordability of residents of purchase currently.

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J. Service Science & Management, 2010, 3, 373-382
doi:10.4236/jssm.2010.33044 Published Online September 2010 (http://www.SciRP.org/journal/jssm)

Intercity Bus Scheduling for the Saudi Public Transport Company to Maximize Profit and Yield Additional Revenue

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Received April 22nd, 2010; revised May 29th, 2010; accepted July 8th, 2010.

ABSTRACT

The Saudi Public Transport Company (SAPTCO) intercity bus schedule comprises a list of 382 major trips per day to over 250 cities and villages with 338 buses. SAPTCO operates Mercedes 404 SHD and Mercedes 404 RI-IL fleet types for the intercity trip. The fleet assignment model developed by American Airlines was adapted and applied to a sample of the intercity bus schedule. The results showed a substantial saving of 29% in the total number of needed buses. This encourages the decision makers at SAPTCO to use only Mercedes 404 SHD fleet type. Hence, the fleet assignment model was modified to incorporate only one fleet type and applied to the sample example. Due to the increase in the problem size, the model was decomposed by stations. Finally, the modified decomposed model was applied to the whole schedule. The model results showed a saving of 16.5% in the total number of needed buses of Mercedes 404 SHD. A sensitivity analysis was carried out and showed that the predefined minimum connection time is critical for model efficiency. A modification to the connection time for 11 stations showed a saving of 14 more buses. Considering our recommendation of performing a field study of the trip connection time for every station, the expected saving of the total number of needed buses will be about 27.4% (90 buses). This will yield a net saving of 16.44 million Saudi Riyals (USD 4.4 million) per year for SAPTCO in addition to hiring new employees. The revenue analysis shows that these 90 surplus buses will yield about USD 20,744,000 additional revenue yearly.

Keywords: *Fleet Assignment Model, Bus Scheduling, Integer Programming, Transportation Service, Revenue Management*

1. Introduction

1.1. Problem Definition

SAPTCO has 382 intercity major trip departures every day. This excludes the local services and the international services to Egypt, Kuwait, Jordan, Sudan, Qatar, Bahrain, Syria, Turkey, and The United Arab Emirates. This Intercity schedule is produced by considering an existing set of trips, traffic revenue forecasts, available resources such as buses, drivers' base, maintenance shop base, and associated operating cost. SAPTCO is applying an assignment system such that the buses and drivers are assigned to 14 main stations, *i.e.*, each station has its own bus fleet and drivers. According to that system's work regulations, the drivers are assigned to the trip schedule, then, a bus is assigned to one or two scheduled drivers, depending on the length of the trip to operate his (their) scheduled trip. The work regulations require that:

a) Each driver takes a minimum number of hours off work before he takes another trip which may be to another station or to his original (base) station.

b) Each driver has to take one day off work per week.

According to (a) of work regulations, during driver's rest time the bus which is assigned to him cannot be assigned to another driver, the bus is idle at this rest time which can sometimes be more than 12 hours, whereas, (b) means that the bus is idle for a whole day during its driver's rest. Since the trips are scheduled for all week days, an additional number of buses are required to cover this rest day for all drivers. These additional buses are estimated to be 16.6% of the daily used scheduled buses.

At SAPTCO, two points of view can be identified: one is expressed by the maintenance department who wants to retain this existing assignment system. The other point of view is expressed by the operations department who seeks "better" assignment system. This research paper proposes a new assignment system which takes into account maximizing the utilization of any bus in the fleet. This means that it should take a few hours (three are proposed for the most stations) after the bus's arrival at any station to be prepared (e.g., maintenance checking, bus cleaning... etc.) for operating any other scheduled trip by any scheduled driver for this trip. In contrast, the proposed assignment system first assigns buses to the trips schedule, and then assigns drivers to those scheduled buses.

1.2. Literature Review

The fleet assignment problem for airline industries addresses the question of how to best assign aircraft fleet types to an airline's schedule of flight legs. A flight leg is defined as a journey consisting of a single take off and landing, and thus constitutes the smallest unit of operation that can be assigned an aircraft. A flight schedule is a set of light legs with specified departure and arrival airports and times (arrival times can be fleet specific). A fleet assignment is a function that assigns a fleet type to each flight leg [1].

The scale and complexity of fleet assignment problems and their large cost implications have motivated the development of optimization-based methods to solve them. Abara [2] presents a formulation for a general flight Network based on a partial enumeration of "feasible turns", that is, connection opportunities between pairs of flight legs. The model was formulated and solved the fleet assignment problem as an integer linear programming model, permitting assignment of two or more fleets to a flight schedule simultaneously. The objective function of the model can take a variety of forms including profit maximization, cost minimization, and the optimal utilization of a particular fleet type. Several departments at American Airlines use the model to assist in fleet planning and schedule development.

Subramanian *et al.* [3] developed a model for Delta Airlines that assigns fleet types, not individual aircraft tail numbers, to the flight legs. They showed that actual aircraft are routed after the model is solved to ensure that the solution is operational. Because of the hub-and-spoke nature of operations and large fleet sizes, it is always possible to obtain a feasible tail routing from the assignment recommended by the model.

Kontogiorgis and Acharya [4] developed schedule planners for US Airway that balanced between meeting weekend passenger demand, which is different from weekday demand, and also minimize the costs of realigning airport facilities and personnel that we would incur by changing fight patterns too much. They built a specialized fleet-assignment model and integrated it into a graphical environment for schedule development. The US Airway's planners used the system to create safe, profitable, and robust flight plans.

Rexing *et al.* [5] developed a generalized fleet assignment model for simultaneously assigning aircraft types to flights and scheduling flight departures. Their model, a simple variant of basic fleet assignment models, assigns a time window to each flight and then discretizes each window, allowing flight departure times to be optimized. Because problem size can become formidable, much larger than basic fleet assignment models, they developed two algorithmic approaches for solving the model.

Ahuja *et al.* [6] developed a new approach that is based on generalizing the swap-based neighborhood search approach of Talluri [7] for FAM, which proceeds by swapping the fleet assignment of two flight paths flown by two different plane types that originate and terminate at the same stations and the same times. An important feature of their approach is that the size of our neighborhood is very large; hence the suggested algorithm is in the category of very large-scale neighborhood search algorithms.

Sherali and Zhu [8] proposed a two-stage stochastic mixed-integer programming approach in which the first stage makes only higher-level family-assignment decisions, while the second stage performs subsequent family based type-level assignments according to forecasted market demand realizations. By considering demand uncertainty up-front at the initial fleeting stage, they injected additional flexibility in the process that offers more judicious opportunities for later revisions. They conducted a polyhedral analysis of the proposed model and developed suitable solution approaches. Their results of some numerical experiments were presented to exhibit the efficacy of using the stochastic model as opposed to the traditional deterministic model that considers only expected demand, and to demonstrate the efficiency of the proposed algorithms as compared with solving the model using its deterministic equivalent.

Jacobs *et al.* [9] presented a new methodology for incorporating origin and destination (O&D) network effects into the fleet assignment process. The methodology used a decomposition strategy to combine a modified version of a leg-based fleet assignment model (Leg-FAM) with the network flow aspects of probabilistic O&D yield management. By decomposing the problem, the nonlinear aspects of the O&D market effects and passenger flow were isolated in O&D yield management and incorporated in FAM using linear approximations to the total network revenue function.

Barnhart *et al.* [1] presented a subnetwork fleet assignment model that employs composite decision variables representing the simultaneous assignment of fleet types to subnetworks of one or more flight legs. Their formulation is motivated by the need to better model the revenue side of the objective function. They presented a solution method designed to balance revenue approximation and model tractability. Computational results suggested that the approach yields profit improvements over comparable models and that it is computationally tractable for problems of practical size.

In addition to the above literature reviews, many local public transport studies that were done for SAPTACO were reviewed.

The main objective of this paper is to evaluate the two points of view of the maintenance department and the operations department through developing a new fleet assignment model (new bus schedule).

In next section, the fleet assignment problem (the proposed assignment system) is formulated and solved as an Integer Linear Programming (ILP) problem. This was done by adapting the fleet assignment model developed at American Airlines [2]. Section 3 shows the result of the assignment model application on a sample example and the whole schedule. It also shows model efficiency, cost analysis, sensitivity analysis and revenue management that are conducted for both existing and proposed assignment systems. Section 4 summarizes and identifies the main findings and conclusions. Finally, Section 5 gives some directions for futher reaearch.

2. The Assignment Model

The existing assignment system, first, assigns the drivers to the service schedule, then assigns a bus to one or two scheduled drivers to operate his (their) scheduled trip in this way the bus and the driver is one unit that cannot be separated even at the driver's rest time. Therefore, a proposed assignment system should take into account splitting this unit to maximize the utilization of any bus in the fleet. In another words, the proposed system should first assign the buses to the service schedule, then assign drivers to those scheduled buses. This means that the bus can be used by more than one or two scheduled drivers during one day cycle. This can be done by taking into account after the bus finished its scheduled trip to any station , it should take a few hours (three are proposed by maintenance department for most stations) to be prepared (e.g., normal maintenance checking, bus cleaning,...etc.) to operate any other scheduled trip by any scheduled driver for this trip. In case of major maintenance repair that takes more than three hours, the bus should be replaced by another unscheduled bus.

To design this proposed assignment system, the fleet assignment model developed at American Airlines was adapted. The goal of our fleet assignment model is to assign as many trip segments as possible in the SAPTCO's intercity bus schedule to one or more bus fleet types. (SAPTCO operates Mercedes 404 SHD and Mercedes 404 RHL fleet types for the Intercity trip) while optimizing some objective (e.g., maximize the utilization of Mercedes 404 SHD fleet type, minimize the total number of needed buses, minimize the cost of imbalance schedule) and meeting sets of constraints (e.g., trip coverage, continuity of equipment, schedule balance, and bus count). The model uses integer linear programming to solve the fleet assignment problem. Given a service schedule, with departure and arrival times indicated, it determines which bus trip should be assigned to which bus types to optimize the objective function.

2.1. Model Formulation

2.1.1. Constraints

1) Trip coverage:

After many interviews with the decision makers of maintenance department of SAPTCO, it was determined that a minimum of three hours time will be enough for any arriving trip at a specific station to finish normal bus maintenance checking and bus cleaning, so that this trip (bus) can be connected with any departing trip from the same station whose departure time permits this minimum three hours for connection. We will refer to Trip-to-Trip by turns. Typically, an arriving trip can turn to more than one departing trip. **Figure 1** shows four arriving trips to the Riyadh station (Trips: 1318. 763, 765, and 1931) and five departing trips (Trips: 768, 772, 1313, 1317, and 1948) from the same station. Allowing a minimum connection time of three hours, 22 turn variables per bus type are possible as follows:

0000-768, 0000-772, 0000-1313, 0000-1317, 0000-1948, 1318-772, 1318-1313, 1318-1317, 1318-1948, 763-772, 763-1313, 763-1317, 763-1948, 765-1313, 765-1317, 765-1948, 1931-1317, 1931-1948, 1318-0000, 763-0000, 765-000, 1931-0000, where the turn 1318-0000 represents a termination trip in Riyadh, *i.e.*. the bus that operated trip 1318 should be overnighting in Riyadh and cannot be connected to any other departing trip on the same day. While, the turn 0000-768 represents an origination trip from Riyadh, *i.e.*, the bus that will operate trip 768 is already in the Riyadh station from last night and not arriving from any other station on the same day.

Now, we can define the decision variable $X_{i,j,k}$ to represent a feasible turn where the arriving trip i turns to the departing trip j on bus type k. If $i=0$, then j is a sequence origination and, if $j=0$, then i is a sequence

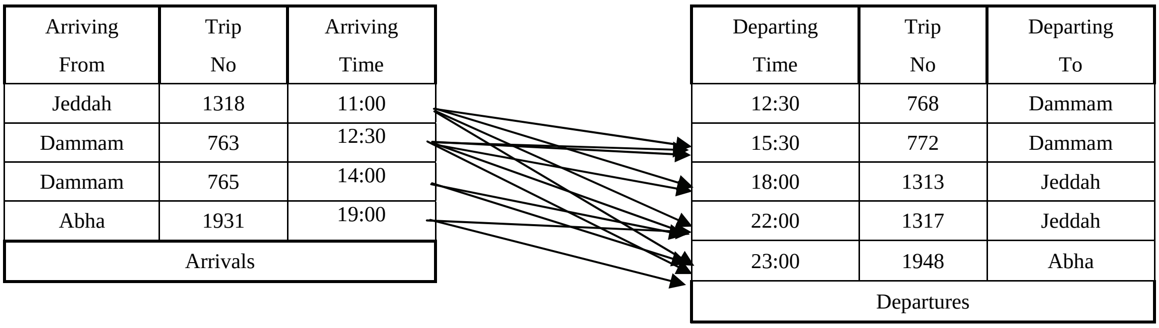

Figure 1. Four arrivals and five departures trips (Riyadh Station).

termination where sequence represents the daily routing for a bus. If $k=1$ represents Mercedes 404 SHD bus type and $k=2$ represents Mercedes 404 RHL bus type, then $X_{1318.772.1}=1$ means that the trip 1318 arriving to Riyadh from Jeddah can be turned (connected) to trip 772 departing from Riyadh to Dammam using Mercedes 404 SHD bus type. While $X_{1318.772.1}=0$ means that the trip 1318 cannot be connected to trip 772 using Mercedes 404 SHD bus type (*i.e.*, it may use Mercedes 404 RHL bus type or connected to any trip other than 772). Hence, $X_{i,j,k}=\begin{Bmatrix}0\\ or\\ 1\end{Bmatrix}$.

To prevent trips being counted twice, each trip must be served exactly once. That is, each departing trip must be a turn of only one arriving trip or being an originating trip and use only one bus type. This means, for example, neither $X_{1318.772.1}=1$ and $X_{763.772.1}=1$ nor $X_{1318.772.1}=1$ and $X_{1318.772.2}=1$ can happen. Suppose that T represents the total number of scheduled trips, then the first constraint can be written as follows:

$$\sum_{i=0}^{T}\sum_{k=1}^{k=2} X_{i,j,k} \quad \forall j \tag{1}$$

2) Continuity of equipment:

To assure the integrity of the network, each trip being served must begin (sequence origination or continued from another trip) and end (sequence termination or turn into another trip) on the same bus type. This constraint can be stated as follows:

$$\sum_{i=0}^{T} X_{i,l,k} = \sum_{j=0}^{T} X_{l,j,k} \quad \forall l,k \tag{2}$$

3) Schedule balance by station and bus type:

An excess of arrivals over departures at a given station results in a sequence origination shortage; the reverse situation leads to a sequence termination shortage. **Figure 2** shows an example of this case where there are three sequences for three stations Riyadh, Dammam, and Jeddah: 1350-771-1317, 761-1309-1352, 765-1313. Riyadh station is balanced while Dammam and Jeddah Stations are not. Jeddah station has one origination trip represented by OR (trip 1350) and two termination trips represented by TE (trip 1313 and trip 1317), *i.e.*, there is a sequence origination shortage at Jeddah station. There is a reverse situation at Dammam station where a sequence termination shortage happens.

A difference between the schedule's total departures and total arrivals represents a physical imbalance. To overcome this imbalance, we introduce the following decision variables:

O_{sk} = No. of origination shortages at station s for bus type k.

R_{sk} = No. of terminations shortages at station s for bus type k.

Therefore, the sum of sequence originations and the origination shortage variable (O_{sk}) must be equal to the sum of sequence terminations and the termination shortage variable (R_{sk}) for each station s and bus type k. Hence, the third constraint can be written as follows:

$$\sum_{j\in D_s} X_{0,j,k} + O_{sk} = \sum_{i\in A_s} R_{sk} \quad \forall k,s \tag{3}$$

where

D_s = Set of departures from station s

A_s = Set of arrivals at station s.

4) Bus count

The main objective of the assignment model, as we will see later, is to minimize the number of buses used. Therefore, if the schedule is too small for the available buses, only the number needed should be used. In contrast, if the schedule is too large, then the available buses of the two types should be exhausted before any additional buses can be added. The constraint can be stated as follows:

$$\sum_{j=1}^{T} X_{0,j,k} - E_k \le M_k \quad \forall k \tag{4}$$

where

M_k = Number of available buses of type k in all

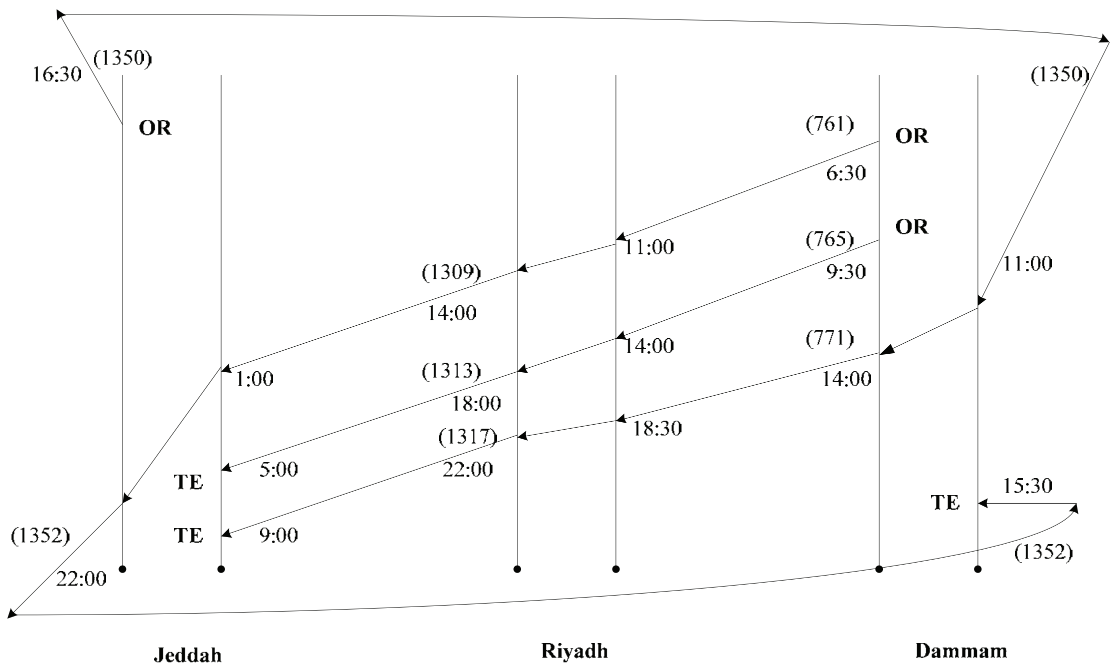

Figure 2. Imbalance schedule.

stations.

E_k = Number of the additional buses of type k in all stations that are needed beyond the available number to cover the service schedule.

2.1.2. Objective Function

After many interviews with the decision makers in the SAPTCO operations department, the following goals that should be satisfied by the model were determine:

1) Mercedes 404 SHD bus type must be used for a specific trip (e.g., Riyadh-Jeddah, Riyadh-Makkah, Riyadh-Madinah, etc). After covering all of these specified trips, it is preferred to use this bus type for any others trips until it is exhausted. Then, Mercedes 404 RHL bus type should cover the remaining trips.

To incorporate this goal into the model the following parameter is defined:

b_{jk} = Benefit of operating trip j on bus type k

where values of b_{jk} for the following cases can be assumed:

- If Mercedes 404 SHD bus type must be used, then $b_{j1} = 4$ and $b_{j2} = 0$.
- If Mercedes 404 SI-1D bus type is preferred to be used, then $b_{j1} = 3$ and $b_{j2} = 2$.

Hence, this goal can be written as:

$$Maximize \sum_{i=0}^{T} \sum_{j=0}^{T} \sum_{k=1}^{K=2} b_{jk} X_{i,j,k}$$

2) A minimum number of buses must be used to minimize the total operation cost or to maximize the total profit (the revenue is fixed). This goal consists of two parts; in the first part, the use of the available buses (the origination trips) must be reduced. In the second, the use of the additional buses (E_k) must be reduced by imposing a large cost or penalty of using it. This can be stated as follows:

$$Minimize \sum_{j=1}^{T} \sum_{k=1}^{k=2} X_{0,j,k} + C_1 \sum_{k=1}^{k=2} E_k$$

where C_1 is a large penalty value, say, $C_1 = 1000000$.

3) Shortages in sequence originations and terminations result in dead-heading and incur costs. To reduce the chance of producing an imbalance schedule, a large penalty value is imposed for the decision variables O_{sk} and R_{sk} in the objective function as follows:

$$Minimize\ C_2 \sum_{s=1}^{S} \sum_{k=1}^{k=2} \left(O_{sk} + R_{sk}\right)$$

where S is the total number of stations and C_2 is a large penalty value , say, $C_2 = 500000$.

Combining all of the above model ingredients, the ILP assignment model is:

ILP:

$$Maximize \sum_{i=0}^{T} \sum_{j=0}^{T} \sum_{k=1}^{K=2} b_{jk} X_{i,j,k} - C_2 \sum_{s=1}^{S} \sum_{k=1}^{k=2} \left(O_{sk} + R_{sk}\right)$$
$$- \sum_{j=1}^{T} \sum_{k=1}^{k=2} X_{0,j,k} - C_1 \sum_{k=1}^{k=2} E_k$$

Subject to:

$$\sum_{i=0}^{T}\sum_{k=1}^{k=2} X_{i,j,k} \quad \forall j$$

$$\sum_{i=0}^{T} X_{i,l,k} = \sum_{j=0}^{T} X_{l,j,k} \quad \forall l,k$$

$$\sum_{j\in D_s} X_{0,j,k} + O_{sk} = \sum_{i\in A_s} R_{sk} \quad \forall k,s$$

$$\sum_{j=1}^{T} X_{0,j,k} - E_k \le M_k \quad \forall k$$

where $E_k, O_{sk}, R_{sk}, and\ E_k$ are decision variables taking the following values:

$X_{i,j,k} = 0,1$ and $O_{sk}, R_{sk}, and\ E_k = 0,1,2,3,...$

3. The Results

3.1. Sample Example Results for Two Fleet Types

To validate the model before its application to the whole schedule, we selected a sample of 40 trips which satisfy all the model requirements. This sample example consists of five main stations: Riyadh, Jeddah, Dammam, Madinah, and Abha, and four minor stations: Bishah, Jawf, Khafji, and Qurayyat. A three-hour period was chosen as minimum time for any arrival trip to turn (be connected) to any departure trip at the same station. Two buses types Mercedes 404 SHD ($K=1$ in the model) and Mercedes 404 RHL ($K=2$ in the model), were used.

The results of this application showed that all constraints were satisfied, that is, for each bus type each departing trip was indeed, a connection (turn) of only one arriving trip or an origination trip which satisfies the first trip coverage constraint. Each arriving trip was turned (connected) to only one departing trip, or it was a termination trip on the same bus type, which satisfies the second constraint. Constraint (4), bus count, was satisfied for each station where the number of origination trips never exceeded the number of the available buses plus the additional ones. **Table 1** shows that the number of origination (orig.), connection (con.), termination (term.), and departure (dep.) trips for each main and minor station where the number of origination trips plus the number of connection trips is equal to the total number of departure trips, while the number of termination trips plus the number of connection trips is equal to the total number of arrival trips. Since the total number of departure trips is equal to the total number of arrival trips for each station and the satisfaction of constraint (3) of the assignment model, in addition to forcing the values of O_{sk} and R_{sk} in the last part of the objective function to be zero through the penalty value

$C_2 = 500000$, then the total number of origination trips is always equal to the total number of termination trips. This means that for any terminated arrival trip, the bus will be overnighting in the station then operate the next day origination trip. This makes a balanced schedule.

To compute the needed number of bused to cover the 40 trips sample example, as shown in **Table 2**, we added the trip time (the time that the trip took from the departure station to the arrival station) and the connection time (the actual time that elapsed for any arrival trip to a specific station to connect another departure trip from the same station) for all trips, then divided these number of hours by 24. That is, the total number of needed buses is given by the following:

$$\begin{aligned}&Total\ number\ of\ needed\ buses\\&= \frac{Total\ trips\ time + Total\ trips\ connection\ time}{24}\\&= \frac{438.75+329.25}{24} = 32\ buses\end{aligned}$$

Using the existing assignment system, the actual number of needed buses was 45 buses of both types. This means 13 (29% saving) buses were saved using the proposed assignment system.

3.2. Model Modification to Incorporate Only One Bus Type (Mercedes SHD 404)

The good saving in the total number of needed buses encourages the decision makers at SAPTCO to decide to use only Mercedes 404 SHD bus type. Therefore, we

Table 1. Summary results of the application of the assignment model on the sample example.

	Main Stations					Minor Stations				Total
	Riyadh	Jeddah	Dammam	Abha	Madinah	Bishah	Jawf	Khafji	Qurayyat	
Orig.	2	1	1	0	0	2	0	2	0	8
Con.	7	4	6	5	3	1	3	0	3	32
Term.	2	1	1	0	0	2	0	2	0	8
Dep.	9	5	7	5	3	3	3	2	3	40

Table 2. Computation of the needed number of buses.

Sequence	Trip No.	Trip Time	Connection Time	Total Time	Station
1	236	5	4	9	Jeddah
2	1502	8.5	10.5	19	Jeddah
3	1350	18.5	15.5	34	Jeddah
4	512	9	10.5	19.5	Jeddah
5	1316	12	6	18	Jeddah
6	1930	13	8.5	21.5	Riyadh
7	762	4.5	3	7.5	Riyadh
8	1305	11	4.75	15.75	Riyadh
9	11.6	14	13	27	Riyadh
10	1962	12	4	16	Riyadh
11	2310	14	3.75	17.75	Riyadh
12	2282	7	7	14	Riyadh
13	2302	17	3	20	Riyadh
14	1204	12	7.5	19.5	Riyadh
15	761	4.5	16.5	21	Dammam
16	2214	3.5	5	8.5	Dammam
17	1250	15	5.5	20.5	Dammam
18	1351	18.5	3	21.5	Dammam
19	2202	17	3	20	Dammam
20	2553	16	8	24	Dammam
21	2208	13	8.5	21.5	Dammam
22	501	9	3	12	Abha
23	1506	3.5	4.5	8	Abha
24	1941	12.75	15.5	28.25	Abha
25	2553	16	7.5	23.5	Abha
26	1949	13	4.25	17.25	Abha
27	1201	12.5	3	15.5	Madinah
28	229	5	15.5	20.5	Madinah
29	1251	16	12.5	28.5	Madinah
30	1507	3	13	16	Bishah
31	1961	12	7	19	Bishah
32	1505	8.5	20.5	29	Bishah
33	2209	14	4	18	Jawf
34	2313	14	9	23	Jawf
35	2210	5	7	12	Jawf
36	2211	5	7	12	Qurayyat
37	2201	17	7	24	Qurayyat
38	2303	17	10	27	Qurayyat
39	2281	7	19.5	26.5	Khafji
40	2213	3.5	9	12.5	Khafji
Total		438.75	329.25	768	
Total no. of buses =	768/24 = 32				

modified the fleet assignment model by deleting the first part of the objective function and let all the decision variables not depend on bus type. This modified model was applied to the same sample example using only Mercedes 404 SHD bus type.

3.2.1. Problem Size and Decomposed Model

As mentioned in Abara's paper, the approximate number of $X_{i,j,k}$ variable decision variables is $5TK$, where T is the total number of trips and K is the total number of fleet (bus) types. There are also $2KS$ shortage variables (O_{sk}, R_{sk}) and K additional bus variables (E_k). To compute the total number of constraints, the first constraint comprise T trip coverage constraints, the second constraint comprises TK continuity of equipment constraints, the third constraint comprise KS schedule balance constraints, and the forth constraint comprises K bus count constraints.

Table 3 shows the actual number of variables and constraints for the application of the original (two bus types used) and modified (one bus type used) models on the sample example. It also show the expected number of decision variables and the number of constraints if the modified model applies to whole schedule which consists of 382 trips and 28 stations.

From **Table 3**, the problem size becomes larger for the application of the modified model to the whole schedule. This encouraged the decomposition of the modified model by station. The assignment results for the three models, original, modified and decomposed, were different but the total connection times were the same (329.25 hours). This means that the three models utilized the same number of buses to operate the given schedule.

3.2.2. Application of the Decomposed Modified Model to the Whole Schedule

SAPTCO' intercity bus schedule comprise a list of 382 major trips per day to over 250 cities and villages utilizing 328 buses of the Mercedes 404 SHD and Mercedes 404 RHL types (using the existing assignment system). This schedule consists of 14 main and 14 minor stations.

From the previous discussion the decomposed modified model was applied to this whole schedule using only Mercedes 404 SHD bus type taking 4 hours as the minimum time for connection in Riyadh and Jeddah stations

Table 3. Problem size for different models.

Models Problem Size	Original Model	Modified Model	
	Sample Example	Sample Example	Whole Schedule
Total No. of Variables	432	21 6	1 967 (expected)
Total No. of Constraints	140	90	793

and three hours for other stations, The results showed that all constraints were satisfied as mentioned in the sample example and the total number of needed buses to cover the whole schedule was 274 buses of Mercedes 404 SHD type.

1) Model Efficiency:

The existing assignment system uses 328 buses to cover the 382 trips per day. The total trip time (working hours) was 2951 hours. For the proposed assignment system, the total connection times (lay-over hours) was 3625 hours. To compare the existing and proposed assignment system, the following measures of effectiveness (MOE) were computed:

For the existing assignment System:

Average working hours per bus per day $= \frac{2951}{328} = 9$ hours

Average lay-over hours per bus per day = 15 hours

Percent of daily working time $= \frac{9}{24} \times 100 = 37.5\%$

For the proposed assignment system:

Average working hours per bus per day $= \frac{2951}{274} =$ 10.77 hours

Average lay-over hours per bus per day $= \frac{3625}{274} =$ 13.23 hours

Percent of daily working time= $\frac{10.77}{24} \times 100 = 44.88\%$

The increase in the percent of daily working time = 7.38%

Model efficiency $= \frac{328 - 274}{328} = 16.5\%$

The above results shows that increasing the average working hours per bus per day using the proposed assignment system by only 1.77 hours (or 7.38%) saved 54 buses (16.5% of the existing used buses).

2) Sensitivity Analysis

The predefined minimum connection time (four hours for Riyadh and Jeddah stations and three hours for others stations) was judgmental and was not based on any field studies. The predefined minimum connection time for 11 stations (most of them are minor stations that the people at SAPTCO think that they really do not need three hours as a connection time) were reduced to one hour instead of three hours and the proposed assignment model was reapplied to these stations. Then, the total real connection time for each station were computed and compared to that before modification. The results showed that there was a saving of 336 hours for the 11 stations. This means that 14 more buses were saved. Moreover, the predefined minimum connection time for Abha and Makkah stations were reduced to two hours and the results of the reapplication of the proposed assignment model showed that there was a saving of 3 more buses. This gives us the following MOE for the proposed assignment model:

Average working hours per bus per day $= \frac{2951}{257} =$ 11.48 hours

Average lay-over hours per bus per day $= \frac{3217}{257} =$ 12.52 hours

Model efficiency $= \frac{328-257}{328} = 21.6\%$

The more interested results from the above sensitivity analysis are:

- The real connection times varies from its minimum, 3 hours, to more than 20 hours and few of them were 3 hours. This means that the rush demand for maintenance is not really true.
- For Makkah station when the predefined minimum connection was reduced to two hours, only 5 departure trips out of 43 (the total number of departure trips) needed real connection time less than three hours. The same was happen for Abha station where only 5 departure trips out of 33 needed real connection time less than three hours. If these specific departure trips take a high priority for bus checking and cleaning, the reduction of the predefined minimum connection will not be very critical for the maintenance department.
- For Abha station when we try to reduce the predefined minimum connection by one more hour (after it was reduced to two hours), the total connection time was the same as for two hours predefined minimum connection. This means that the predefined minimum connection limit behind it we cannot save any buses

From the above results, by performing a field study of this predefined minimum connection time for every station, the expected saving of the total number of needed buses will be about 90 buses (Model efficiency =27.4%). This will yield a net saving of 16 million Saudi riyals per year for SAPTCO as will be illustrated in the cost analysis next.

3) Cost Analysis

Since the revenues are the same for the existing and the proposed systems as both systems operate the same number of daily trips (*i.e.*, the same intercity schedule), the comparison between both systems concentrate on the operation cost for both systems. The operation costs consist of two parts, the first is the direct (variable) costs which are divided to kilometer cost that equal to 0.32 SR/km and hour cost that equal to 35.15 SR/hr. The second part is the fixed cost which is counted for the daily (24 hours) use of the bus. This fixed cost estimated to be 668 SR/day. That is, for example, a trip from Riyadh to Jeddah take about 12 hours and its length about 1000 kilometers will cost:

$$0.32 \times 1000 + 35.15 \times 12 + 668 = 1409.8 \text{ SR}.$$

Since the existing and the proposed systems operate the same number of kilometers and the same number of hours, then our comparison will depend on the fixed cost that depend on the number of buses used. The existing system use 328 buses to cover the service schedule, while from the model results the proposed system need 238 buses. This means that there is a saving of $(328-238) \times 668 = 60120$ SR/day or about 21.94 million SR per year.

The proposed system incur hiring new employees for bus checking, filing, and reporting bus status during the connection time (the proposed three hours) before another driver operates the bus for the next trip. The total hiring costs were estimated to be about SR 5.5 million per year. This means the net saving cost will be about SR 16.44 million (USD 4.4 million) per year.

4) Revenue Management

As we mentioned in the cost analysis the revenue from the proposed system is not changed, but as a result of the proposed system, SAPTCO will have 90 buses surplus and these buses can be utilized to yield new additional revenue as follows using the revenue data in **Table 4**:

- There are seasonal demands for the SAPTCO buses for about four months during a year. Three months for what is called "O'Mara", which is Muslim religion custom, to visit Al Kaaba in Makkah city and its peak demand in Ramadan, Shaban, and Ragab months of Hagree calendar. In these months SAPTCO outsources buses form other transport companies. Using all or part of their surplus buses will yield additional revenue.

Yearly $\textit{Additional Revenue}$ (1)

$= \textit{Number of buses} \times 90\ \textit{Days} \times \textit{bus revenue per day}$

$= 60 \times 90 \times 3800 = \textit{SR}\ 20,520,000 = \text{USD}\ 5,472,000$

- There is also one month that has the highest demand

Table 4. Average daily bus revenue for different trip type.

Trip Type	Revenue/Bus/day
Intercity Trip	SR 2000
International Trip	SR 3800
O'Mara Season Trip	SR 3800
Pilgrim (Hajj) Season Trip	SR 5500
City School or Company Trip	SR 400

for buses during pilgrim (Hajj) season which is also a Muslim religion custom to visit Al Kaaba in Makkah city at least one time in the Muslim person life. In this month they can use their surplus buses instead of outsourcing.

$$\text{Yearly } \textit{Additional Revenue } (2)$$
$$= \textit{Number of buses} \times 30 \textit{ Days} \times \textit{bus revenue per day}$$
$$= 60 \times 30 \times 5500 = SR\ 9,900,000 = \text{USD } 2,640,000$$

- Around the year, there are high demands from others agencies, like schools, manpower companies, and others small companies to outsourcing buses from SAPTCO. Using some of their surplus buses will yield new revenue.

$$\text{Yearly } \textit{Additional Revenue } (3)$$
$$= \textit{Number of buses} \times 240 \textit{ Days} \times \textit{bus revenue per day}$$
$$= 60 \times 240 \times 400 = SR\ 5,760,000 = \text{USD } 1,536,000$$

- Around the years there are a medium demand for international trip to Egypt, Jordon, Iraq, Syria, Lebanon, and Yemen countries

$$\text{Yearly } \textit{Additional Revenue } (4)$$
$$= \textit{Number of buses} \times 365 \textit{ Days} \times \textit{bus revenue per day}$$
$$= 30 \times 365 \times 3800 = SR\ 41,610,000 = \text{USD } 11,096,000$$

- Therefore the total yearly additional revenue will be:

$$\textit{Total } \text{Yearly } \textit{Additional Revenue}$$
$$= \textit{Additional Revenue } (1) + \textit{Additional Revenue } (2) +$$
$$\textit{Additional Revenue } (3) + \textit{Additional Revenue } (4)$$
$$= \text{USD } 20,744,000$$

4. Summary and Conclusions

In this paper, a new intercity bus schedule for the Saudi Public Transport Company (SAPTCO) has developed. Conversely to the existing assignment system, the new assignment system assigns buses to the given intercity bus schedule first, and then assigns drivers to those scheduled buses in such way that maximizes the utilization of buses. The main finding of this application can be summarized as follows:

1) Only 274 out of 328 buses of Mercedes 404 SHD are needed to cover the service schedule (a total saving of 54 buses).

2) By performing a field study of the trip predefined minimum connection time for every station, the expected saving of the total number of needed buses will be about 90 buses.

3) The new schedule system yielded the following for SAPTCO:

- A net saving of USD 4.4 million per year.
- Hiring new employees with no additional cost for bus checking, filing, and reporting bus status during the connection time.
- Additional revenue of USD 20,744,000 per year from the use of the 90 surplus buses.

5. Directions for Further Research

Based on the results and the analysis, directions for further research can be summarized as follows:

1) The new assignment system is based on the given service intercity schedule which may be optimal (it may be built in the spirit of the existing system). This encourages developing a new optimal service schedule and reapplying the assignment model for it.

2) The determination of three hours as a minimum connection time for all station is judgmental and need field studies.

3) The existing drivers' assignment system which used to assign drivers to the scheduled buses need to be adapted to take into account the advantages of the new bus assignment system.

4) Developing a maintenance bus schedule so that bus has its maintenance schedule time depending on the proposed assignment system.

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J. Service Science & Management, 2010, 3, 287-382
Published Online September 2010 in SciRes (http://www.scirp.org/journal/jssm)

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Volume 3 Number 3 **September 2010**

