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LETTER FROM THE EDITOR

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Jim Carland
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INTERNET PRICING: BEST EFFORT VERSUS QUALITY OF SERVICE

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ABSTRACT

This research uses Bertrand methodology to examine the influence of competition between companies that utilize Quality of Service (QoS) pricing strategy versus Best Effort (BE) pricing strategy for Internet Service Providers (ISPs). The Bertrand duopoly price competition model is effective at determining customer's willingness-to-pay and level of internet usage patterns in relation to price paid for service. The model also makes use of a two-part tariff consisting of a fixed rate for Best Effort (BE) service, and a usage-sensitive rate structure for premium QoS. Initial results indicate that an equilibrium market position for each ISP depends on a customer's preference for QoS and the price of BE service. Implementation of this research using a game simulation revealed an analytical framework for iterative, short-term, future QoS Internet pricing strategies.

INTRODUCTION

Since the commercialization of the World Wide Web (WWW), Internet Service Providers (ISPs) have expanded their service simply by increasing their number of subscribers. Traditionally, ISPs offered only one class of service for all types of traffic. They treated traffic indifferently with no discrimination among the types of traffic, no guarantee for timely delivery, and a realistic possibility of traffic loss. This type of Internet service has generally been known as "Best Effort" (BE).

With the rapid growth of e-commerce, demand for various classes of Internet services is expected to grow and diversify. Customers with real time and business-critical data applications are searching for improved levels of service, or Quality of Service (QoS) connections to the WWW. Compared to BE, ISPs are now looking to premium QoS class connections for customers. These new classes could include, but are not limited to, a class to guarantee timely delivery, a class to ensure no traffic loss, a class for delivery confirmation, or any combination of all classes.

These developments are harbingers for the future. First, there will be at least two classes of service in the Internet market: BE and QoS. Since QoS includes BE service as its lowest class of service, the superiority of QoS to BE results in vertical product differentiation. Second, it is reasonable to expect a change in the pricing paradigm from non-metered, flat rate, unlimited access user pricing to usage-sensitive metered pricing for higher valued QoS.

ISPs are simultaneously competitors and cooperators. On one hand, they are competitors for market share. On the other hand, they are cooperators that provide universal, global connectivity. Thus, one ISP's actions influence another's actions. Furthermore, end-to-end QoS could not be established without strong cooperation among ISPs. To behave accordingly suggests game theoretic modeling, i.e., each player in the game is a competitor, and their interactions provide motivation for strategic decisions.Under traditional Internet pricing with unlimited access and flat rate monthly payments, users want to take as much bandwidth as they can within their access capacity. This leads to a "tragedy of the commons" phenomenon which can be overcome through usage-sensitive pricing. Therefore, we propose a simulation methodology to explain an ISPs' equilibrium behavior in a futuristic QoS market. To implement our approach, we employ a Bertrand price competition model to determine a customer's willingness-to-pay and Internet usage patterns. The Bertrand model also includes two different pricing schemes: one for an ISP with traditional unlimited access, flat rate pricing for BE, and another for an ISP with a two-part tariff consisting of a fixed rate for BE, plus a usage-sensitive pricing strategy for QoS.

The research is structured as follows. First, we present the differentiated service initiative of AT&T and WorldCom. Then, we provide a literature review forming a foundation for the research extension, followed by economic assumptions for pricing, consumer demand and usage for the industry. Next, cost, revenue and profit functions for the methodology are discussed. Finally, the proposed simulation and optimization approach, as well as the behaviors of ISPs at an equilibrium point are presented. To conclude, preliminary results and issues for future research are offered.

SUPPORTING INDUSTRY ACTION

Recently, large service providers like AT&T and WorldCom announced in the summer of 2001 that they would start providing Internet customers with "Class of Service" (CoS) connections using Multi-Protocol Label Switching (MPLS) and Differentiated Services. These CoS-based services consisted of four priority level classes: Platinum, Gold, Silver, and Bronze. Customers requiring applications for voice and video would probably choose the Platinum, or highest priority level of service, while other customers requiring only applications for HTTP and e-mail traffic might choose the Bronze, or lowest priority level of service (i.e. BE). Customers with business critical data applications might choose an intermediate priority level, namely Gold or Silver. However, these announced service levels were limited to connections completely contained in the carriers' own networks.

Also in 2001, the Florida Multimedia Internet Exchange (FMIX), managed by Bell South, announced a plan to be the first Network Access Point to use an MPLS interconnection among different providers. To do this, FMIX faced many new challenges with QoS interconnections, such as pricing, class matching between providers, as well as managing the disclosure of network information for end-to-end quality guarantees.

SUPPORTING LITERATURE

Our work builds upon recent research by Stahl, Whinston and Zhang as well as Gupta, Linden, Stahl and Whinston, where a simulation-based approach to a duopoly ISP environment was studied. Both studied the affects of BE, flat rate versus usage-based pricing. Stahl et. al (1998) found that when a company like AOL imposes a fee to maximize profits, dynamic usage pricing increased profits five times, while network-wide social benefits increased seven times. Gupta et. at. (2001) also showed that usage-based pricing enhanced system-wide benefits overall. We extend these research efforts to incorporate pricing guidelines for premium QoS choices for ISPs which could easily become a de-facto environment for the Internet in the near future.

In addition, we utilize Bertrand's competitive model to analyze what is considered to be an industry of narrow competition (Bertrand, 1883). Other researchers make use of a Cournot model to analyze the Internet industry, which is a reasonable assumption if a homogeneous service with limited capacity exists (Baake and Wichmann, 1988; Shin et. al., 2002a; Shin et. at., 2002b). Like Stahl et. al. and Gupta et. al., our model also assumes a duopoly in the Internet Access market. However, in our analyses, the service is not homogeneous and capacity is only briefly limited by its chosen queuing medium. We therefore believe that a Bertrand model better suits our approach.

Finally, it is generally known that when one firm's market penetration reaches approximately 60%, the market usually experiences price competition. This has been shown to exist in the radio, television and video cassette recorder markets. With this in mind, recent research indicates that U.S. online households were expected to surpass the 60% mark by the end of 2002 (Vanston, 2002). Hence, there is a strong probability that ISPs will wage a price war in the near future.

ECONOMIC CONDITIONS

In the following three subsections, information pertaining to the development of price, demand and usage functions is presented for model formulation. All are considered parameter inputs for simulation.

Pricing Functions

One important characteristic of the industry is that ISPs are competing with each other for market share. Thus, they are trying to maximize their own profits based on the belief that the other ISP's price is fixed. To model this behavior, we assume that there are only two service classes, a BE class and a premium QoS class. In addition, there is no quality difference among each ISP's QoS class, thus customers are indifferent as to whether they will consume QoS from ISP1 or ISP2. It is also assumed that there are two prices to enter the Internet access market:

(1) Access Price (F) for a right to connect to an ISP's network (a fixed price), and
(2) Usage Price (r) for the volume of Internet usage per hour (a variable price).

The price structure for each ISP can be expressed as:

(1) P1(F1, r1) for ISP1, and
(2) P2(F2, r2) for ISP2.

We further assume that ISP1 uses a flat rate pricing scheme, which can be reduced to P1(F1, 0), where the customers of ISP1 pay only $F1/month regardless of traffic type and volume of their connection hours, while the premium QoS of ISP2 incurs both access and usage price components.

Some have called this type of pricing inefficient because the added fixed charges may deter some users who, at marginal cost prices, would be willing to join the network and consume (Cawley, 1997). Cable television pricing refutes this charge. In that industry there is a fixed price to watch "basic" programming and an additional usage charge for high-valued programs that are handled on a "pay-per-view" basis.

The two-part tariff in our methodology has a similar form to the pricing scheme used by the Cable Television industry. The fixed part lump-sum fee is the right to use the lowest class of service, and the variable part is for the consumption of the premium class of service. Someone who only wants to use the "basic" service pays only the fixed part lump-sum fee. To obtain high-valued programming, the user must first purchase "basic" (BE) service to incur the premium "pay-per-view" (QoS) service.

Demand as a Function of a Customer's Willingness-to-Pay

To capture consumer demand, a recent United States General Accounting Office report was used. Its purpose was to study Internet usage. One of the questions asked was: "*About how much do you pay per month to access the Internet from your home?*" Although this question does not provide a customer's willingness-to-pay for Internet access, we can use the data as a proxy for consumer demand. Table 1 presents the distribution of respondents.

Table 1: Household Expenditure for Internet Access
(USGAO, 2001)

$0	*~$5*	*~$10*	*~$15*	*~$20*	*~$30*	*~$40*	*~$50*	*$50 an up*
8.9%	1.4%	3.8%	8.3%	21.0%	31.7%	11.1%	8.7%	5.1%

In addition, demand must be differentiated between BE service and premium QoS class. According to Gal-Or (1983; 1985), when a product is differentiated on the basis of quality, and each consumer is assumed to purchase only one unit of the product, the consumers' willingness-to-pay (W) is assumed to be dependent upon their taste factor (X) and a quality level (M) for the product. As a function, a consumer's willingness-to-pay takes the form:

$$W(X,M) = f(X)*M, \text{ where}$$

$$W_X > 0,\ W_M > 0,\ W_{MX} > 0,\ W_{MM} \leq 0, \text{ and } W_{XX} \leq 0.$$

We further assume that the bandwidth needed for a specific class determines the quality level of that service, and we assume the bandwidth of the high quality class is at least twice as much as that of low class service, i.e, $M_{QoS}/M_{BE} = 2$. Therefore, in our model the willingness-to-pay for QoS (W_{QoS}) is twice as much as that of BE service (W_{BE}).

Customer Usage

The methodology proposed by this research also heavily depends on Internet usage patterns. To capture consumer usage, the same United States General Accounting Office report was consulted. One of the other survey questions asked: *"On average, how many hours per week do you and all your members of your household spend on the Internet from your home?"* Table 2 presents the distribution of respondents, which directly reflects usage data.

Table 2: Internet Usage Distribution (hrs/wk)
(USGAO, 2001)

0-4 hrs	*4-10 hrs*	*10-15 hrs*	*15-25 hrs*	*25-40 hrs*	*40-60 hrs*	*60-90 hrs*
6.3%	12.1%	19.4%	29.3%	19.8%	6.3%	6.9%

COST, REVENUE AND PROFIT FUNCTIONS

First, we know that cost is highly dependent upon the number of usage hours in each of the two classes. Previous research suggests that in the absence of price-based differentiation, users will choose the highest quality level regardless of traffic type (MacKie-Mason and Varian, 1995). Under this scenario all of the customers of ISP1 should choose the premium QoS class. However, according to parameter r2 of our model, customers of ISP2 choose a% for premium QoS class service and (1-a)% for BE class service.

Also, the cost structure of the Internet industry is characterized by a large, up-front sunk cost and near zero short run marginal cost. It is well known that, with a congestion-free network, the cost to carry or process an additional minute of Internet traffic approaches zero, because the incremental cost is near zero (Frieden, 1998). When an ISP provides for QoS traffic, he needs additional equipment, higher skilled labor, and must plan for a significant increase in operating cost (mainly for monitoring, billing and collection). Hence, we assume that each ISP incurs the same amount of equipment and human cost, so we do not include these two cost factors in our model. However, we have already assumed that the bandwidth requirement of QoS is twice that of BE service, but the cost difference between the two is far more than double. Considering a scaling effect, we propose $0.01 per hour as the cost of BE service, and $0.10 per hour as the cost for premium QoS. Formulations for the two ISP cost functions, ISP1 Cost and ISP2 Cost, are developed below.

(1) ISP1 Cost=$0.1/hr*4.3 wks/mon*S(ISP1's hrs/wk usage)
(2) ISP2 Cost=[($0.01/hr*(1-a)%)+($0.1/hr*a%)]*(4.3wks/mon*S(ISP2's hrs/wk usage)

Next, revenue functions for the two ISPs are developed. Each revenue function simply price multiplied by quantity.

(1) ISP1 Revenue = F1 * q1, where
F1 is the unlimited QoS connection flat rate, and
q1 is the number of ISP1's subscribers.
(2) ISP2 Revenue = (F2 * q2) + S(h_{QoS} * r2), where
F2 is the fixed rate for the unlimited BE connection,
q2 is the number of ISP2's subscribers,
h_{QoS} is the S(total connection hours of ISP2's subscribers)* a%, and
r2 is the QoS connection rate per hour.

Finally, profit functions are easily developed as revenue minus cost. In our price model, we assume F1 to be higher than F2 since F1 covers both the fixed and variable pricing components. Each ISP's profit function is shown below.

(1) ISP1 Profit = ISP1 Revenue – ISP1 Cost, and
(2) ISP2 Profit = ISP2 Revenue – ISP2 Cost.

PROPOSED SIMULATION AND OPTIMIZATION

Simulation of the methodology begins by determining consumer demand. To do this, we employ a Random Number Generator (RNG) with the empirical distribution of Table 1 to obtain specific willingness-to-pay values. To determine consumer usage, we employ a two-stage RNG method based on the empirical distribution from Table 1 and the piecewise uniform distribution from Table 2.

Table 3 below summarizes the parameters and suggested ranges for the proposed simulation model.

Table 3: Suggested Simulation Input Parameters

Parameter	*Suggested Range*
W_{BE}	\$0 to \$50
W_{QoS}	\$0 to \$100
F1, F2	\$10, \$15, \$20, …, \$100
a	20%, 30%, 40%, 50%, 60%, 70%
r2	\$0.3, \$0.5, \$0.7, \$0.9, \$1.1, \$1.3
h	0 to 387 hrs/mon (4.3*90)

Next, customers are assigned willingness-to-pay values (W_{BE} and W_{QoS}) along with a value for their Internet usage hours (h), which are generated by the RNGs described above. We assume that customers are aware of each ISP's pricing strategy, and that they choose their premium QoS provider to optimize their benefit. At the same time, each ISP also knows its competitor's pricing strategy and can construct the best choice among all known combinations of pricing strategies of ISP1 and ISP2.

With assigned values for W_{BE}, W_{QoS} and h, each consumer is able to calculate his net benefits from the consumption of premium QoS, i.e., the difference between the willingness-to-pay for QoS and price of each ISP. For example:

(1) $Net1 = W_{QoS} – F1$ by consuming QoS from ISP1, and
(2) $Net2 = W_{QoS} – (F2 + (h_{QoS} * r2))$ by consuming QoS from ISP2.

If both Net1 and Net2 are below zero, a customer will not buy from either QoS provider. If Net1 or Net2 is greater than zero, the customer will choose the ISP that will give him a higher net benefit value. Thus, if Net1 > Net2, the customer will choose ISP1, otherwise he will choose ISP2.

According to Bertrand's model, ISP1 will choose a price, F1, for its optimal profit assuming ISP2's price is fixed. ISP2 will also choose a price, F2 and r2, for its optimal profit under the assumption that ISP1's price is fixed. Output from the simulation calculates all possible profits of ISP1 and ISP2. The best response profit for each ISP is then chosen (a Nash equilibrium by definition).

In our methodology, we strive to find an optimal pricing strategy for total profit through access price competition (F1 and F2) holding r2 constant. We then iterate the process, each time using an increasing value for r2 until equilibrium occurs. Lastly, the final equilibrium point occurs at the intersection point of each ISP's best response function. Thus, by comparing ISP1 Profit [F1*, (F2, r2)] and ISP2 Profit [F1, (F2*, r2)], we find the simulation methodology's equilibrium at (F1*, F2*).

Trials of the simulation methodology have been easily conducted using the CSIM Simulation Package on the platform of Visual C++ 6.0.

CONCLUSIONS

Our proposed methodology indicates that an ISP's optimal QoS pricing strategy can be determined by the price of BE service along with a customer's preference toward the premium QoS option. Initial data indicates F1 = \$30, and F2 = \$10 with r2 = \$1.10. Generally speaking, customers with small amounts of premium QoS usage prefer the two-part tariff. Conversely, customers with larger amounts of QoS usage prefer a flat rate pricing scheme. At what point and how we separate the two is what matters.

Many scholars and industry experts indicate that over-provisioning and traffic engineering cannot successfully provide premium QoS without an appropriate pricing scheme. Therefore, the introduction of usage-sensitive pricing into the Internet industry is probably inevitable. Unfortunately, our simulation methodology cannot predict, unconditionally, which pricing strategy would provide the best market position for an ISP in the future. The problem is too dynamic. As prices change and new competitors enter or leave the market, our methodology can be implemented to determine an optimal, short-term pricing strategy. As conditions continue to change, the process can be iterated with newer data to provide a more current strategy.

To conclude, this research provides a foundation for simulating pricing strategies in the ISP market. In future empirical research, we plan to incorporate more in-depth factors such as time-sensitive data, more choices for usage prices, and consumer taste and quality for ISP choice. Consumer taste and quality variables would provide us with other elastic willingness-to-pay factors. We realize that our current assumption of "2" for the willingness-to-pay factor is somewhat rigid. This, along with several of the factors listed above will certainly provide greater sensitivity analyses, and possibly lead to an improved methodology.

REFERENCES

Baake, P. & T. Wichmann (1999). On the economics of Internet peering. *Netnomics*, 1 (1), 89-105.

Bertrand, J.L.F. (1883). Theorie Mathematique de la Richesse Sociale. *Journal des Savants*, 67, 499-508.

Cawley, R.A. (1997). Interconnection, pricing, and settlements: Some healthy jostling in the growth of the Internet. In Kahin, B. & J. Keller (1997). *Coordinating the Internet* (pp. 346-376). Boston, Massachusetts: MIT Press.

Frieden, R. (1998). Without public peer: The potential regulatory and universal service consequences of Internet Balkanization. *3 Virginia Journal of Law & Technology 8*, available at http: //vjolt.student.virginia.edu/.

Gal-Or, E. (1983). Quality and quantity competition. *The Bell Journal of Economics*, 14(2), 590-600.

Gal-Or, E. (1985). Differentiated industries without entry barriers. *Journal of Economic Theory*, 37(2), 310-339.

Gupta, A., L. Linden, D. Stahl & A. Whinston (2001). Benefits and costs of adopting usage-based pricing in a subnetwork. *Information Technology and Management*, 2(2), 175-191.

MacKie-Mason, J.K. & H.R. Varian (1995). Pricing congestible network resources. *IEEE Journal of Selected Areas in Communications*, 13(7), 1141-1149.

Shin, S., H. Correa & M.B.H. Weiss (2002a). A game theoretic modeling and analysis for Internet access market. *International Telecom Society 2002 Conference*, Seoul, Korea.

Shin, S., M.B.H. Weiss & H. Correa (2002b). Internet QoS market analysis with product differentiation theory. *International Telecom Society 2002 Conference*, Seoul, Korea.

Stahl, D. A. Whinston & K. Zhang (1998). A simulation study of competitive Internet pricing: AOL flat rates versus GSW usage prices. *Proceedings of the first International Conference on Information and Computation Economies*, 68-76.

USGAO (2001). *Characteristics and Choice of Internet Users*. United States General Accounting Office publication GAO-01-345.

Vanston, L.K. (2002). *Residential Broadband Forecasts*. A white paper by Technology Futures, Inc., available at www.tfi.com.

GUIDED DESIGN SEARCH AS A DECISION SUPPORT TOOL IN NETWORK DESIGN

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ABSTRACT

A new approach for the solution and analysis of mixed integer programs is presented and applied to a difficult optimization problem found in robust telecommunications network design. This new approach, called Guided Design Search, uses experimental design techniques and Taguchi methods to derive the estimated effects of binary decision variables on the objective function's value. These estimated effects are useful in guiding the optimization search and can also provide additional problem structure information as part of a decision support system. Results from successfully applying this approach to the path restoration form of the joint capacity allocation network design problem are presented, with this new method finding better solutions and proving optimality faster than the industry standard solver.

INTRODUCTION

In the design and maintenance of robust telecommunications networks, a primary goal is to minimize the total amount of capacity (bandwidth) required to meet anticipated demands. A network's *total capacity* consists of its *working capacity* that is utilized during normal, working network operations and additional, *spare capacity* needed for restoration after a network failure, e.g. the loss of communications due to a fiber cut. The *working paths* taken to route communications during normal operation as well as the *restoration paths* utilized after a network failure are part of the solution. Because of the problem's complexity, typical network design methodologies first solve the working capacity allocation problem, and then using this starting point, solve the spare capacity problem. However, the spare capacity problem is dependent upon the working solution, and it is known that a joint working / spare capacity allocation (JCA) approach can reduce total network capacity over this sequential two-stage method (see Iraschko, MacGregor and Grover, 1998; Abou-Sayed, Kennington and Nair 1997; Murakami and Kim 1995 for a detailed analysis of JCA).

Unfortunately, JCA problems are more difficult to solve and analyze and so, in this paper, a preprocessing and analysis technique, Guided Design Search (GDS) (see Lewis, Lewis and White, 2004) is described, integrated with the industry standard linear program solver CPLEX (ILOG Optimization Suite) and promising results presented. In brief, GDS applies Taguchi methods to mixed integer programs in order to efficiently quantify the effects of decision variables on the objective function (see Taguchi, Elsayed and Hsiang, 1989). The JCA objective function value to be minimized is the total amount of network capacity needed subject to meeting demand during normal and failure conditions and the decision variables are whether or not to include an arc in the network. The variable effect estimates derived are used to guide the CPLEX branch-and-bound solver by providing preferred branching directions and to prioritize variable selection. With this additional information, the solution process is improved, with optimality proven in some cases before a feasible solution is found with the default approach. The estimated effects can also be compared to the cost of capacity in order to gauge value, e.g. if all input arc costs are the same, then if the estimated effect of one arc is to increase the total cost of the network, then that arc is not as preferred as another whose average effect is to lower the total cost of the network.

NETWORK MODELING ASSUMPTIONS

A path in a telecommunications network is composed of fiber optic spans (or arcs, in graph terminology) which connect nodes having switching capabilities. The end-nodes of a path determine an origin-destination demand-pair, e.g. two cities are nodes demanding a certain amount of bandwidth to connect them. Whereas, path restoration (see Kennington and Lewis, 2001) creates a new origin-to-destination restoration path for all demands affected by the failure of a fiber optic span, an alternative method of restoration, span restoration, restores communication between the end nodes of the failed span only but is not as capacity efficient as path restoration. An arc's total capacity is both binary and modular (see Doucette, Grover and Martens, 1999), that is, the capacity implemented on a given span is either set to carry up to 192 units (OC-192 level) of bandwidth or zero (the span is not installed).

Let $[N,E]$ be a network with node set $N = \{1, \ldots, n\}$ and arc set $E = \{e_1, \ldots, e_m\}$ of spans between nodes. A *path* in $[N,E]$ is defined as a sequence of nodes connected by spans. A path p^k will have a designated *origin* and *destination* node pair demanding some non-zero level of bandwidth. Let P denote the set of all enumerated paths in $[N,E]$ between given origin-destination node-pairs having non-zero demand. If arc e_i fails, then service will be interrupted for all node-pairs having working paths that contain e_i. For only those paths $p^k \in$ P affected by the failure of arc e_i, we seek to reroute demand between the origin and destination of p^k using the reduced topology $[N, E \backslash \{e_i\}]$. The minimization problem is to find the working and restoration paths $p^k \in$ P yielding the lowest total network capacity costs for all single span failures.

GUIDED DESIGN SEARCH

Taguchi methods stress the early implementation of quality control in the design process in order to improve quality during production with a key element of Taguchi methods being the use of experimental designs, a.k.a. design of experiments (DOE). DOE uses strict design and sampling techniques to efficiently derive estimated effects and is thoroughly documented in various textbooks (recommended texts include Berger and Maurer, 2002; Mason, Gunst, and Hess, 1989; Montgomery, 1984). Alternative sampling methods such as random sampling or varying one-factor-at-a-time generally require more samples and can create biased estimates.

A tenet of Taguchi methods and DOE is the concept of "sparsity of variable effects" which states that when many variables are examined for their effect on a performance parameter, only a relatively few variables will have a major effect. In this paper, the decision variables indicating whether or not to add capacity to an arc are the variables of which only a few are expected to be critical. In industrial applications, DOEs having ten variables are considered large, however a contribution of this paper is the extension of Taguchi methods to problems having thousands of variables.

During the DOE sampling process the critical variables are assigned a zero/one value, then, because these variables are the ones that add tremendously to problem complexity, the problem is very quickly solved and the corresponding objective value recorded. To clarify the GDS approach, the sampling process is described below. Details of the calculations required in experimental designs are not difficult, but beyond the scope of this paper and can be found in DeVor (1992).

1. Let **b** be the zero-one vector corresponding to the decision variables, i.e. $b_j \in \{0,1\}$ indicates whether or not arc e_j is included in the network design;
2. Generate the fractional factorial DOE table, **T**, for **|b|** variables; Note: **T** is an n by m zero-one matrix where n is the number of tests needed for **|b|** variables and m is the number of variables that can be quantified using n tests. An $\{i, j\} \in$ **T** specifies the level at which variable b_j will be set for test run i in the DOE.
3. Let $\mathbf{T}^M$ be the mirror image of **T**. Note: $\mathbf{T}^M$ is created by simply swapping the values of 0 and 1 found in **T** and is used in conjunction with **T** in step (7) to separate the main effect estimates from the two-factor interactions.
4. For each test run i in **T**
    a. Assign values to each of the b_j variables according to row i, column j in table **T**;
    b. Solve the problem and record the value of the objective function as t_i;
5. For each test run i in $\mathbf{T}^M$
    a. Assign values to each of the b_j variables according to row i , column j in table $\mathbf{T}^M$;
    b. Solve the problem and record the value of the objective function as $t^M{}_i$;
6. Using the results from the original and mirror test, calculate the estimate of the average effect, μ_j each variable had on the objective function value;
7. Assign priorities and branching directions to every b_j based on their estimated average effect μ_j ;

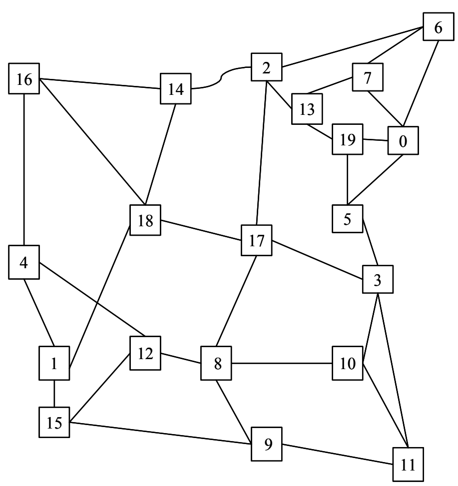
In this paper, step (7) is implemented by integrating the priorities and branching directions within CPLEX. In order to isolate the effects of (7), the same branch-and-bound solver is used, therefore the comparison is strictly between CPLEX using (7) and default CPLEX.

PROBLEM FORMULATION

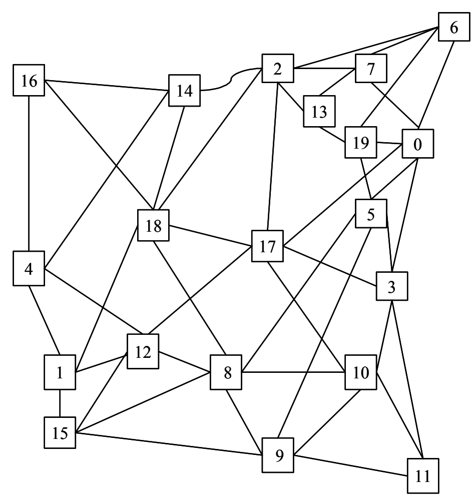
GDS is compared to CPLEX over a range of the following network parameters: network topology type, network connectivity, and number of network demands (see Doucette and Grover, 2001 for a discussion on effects of network connectivity). The networks are constructed by connecting the twenty highest populated U.S. cities in either a mesh or star topology (see Figure 1). The network characteristics used for testing are summarized in Table 1. Output parameters measured are: time to feasible/optimal solutions; objective value; and optimality gap. This controlled, experimental approach minimizes the number of tests needed for comparison of GDS and CPLEX (some tests required days or weeks of CPU time and are difficult to accomplish with limited resources).

The amount of demand will definitely have an effect on total capacity needed to meet those demands. The demand for these tests was allocated according to city population rank so that cities with a higher population have more total demand than cities with a lower population. The total number of variables needed to create the various problem instances ranged from 950 to 4076.

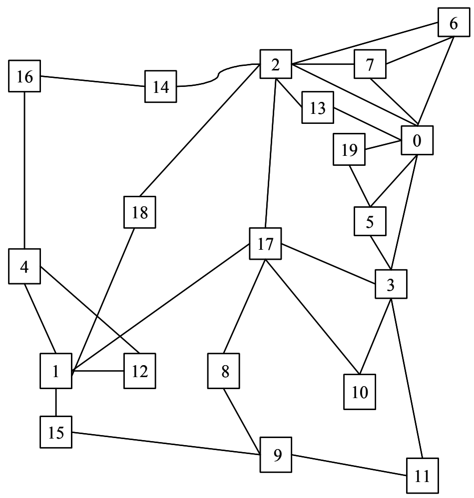
Figure 1: The Four Network Topologies Studied



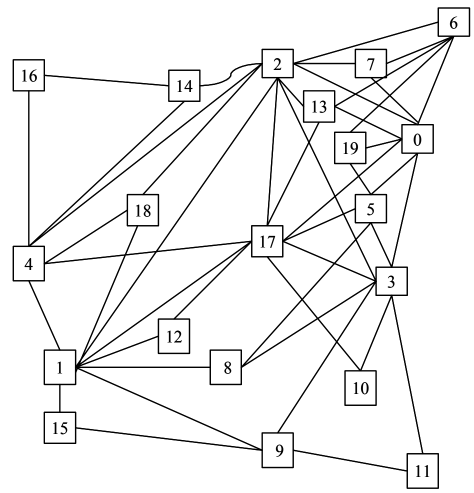
a. Mesh with 32 spans



b. Mesh with 45 spans



c. Star with 32 spans



d. Star with 45 spans

Table 1. Test Network Characteristics

	Test Characteristics		
Test ID	# Arcs	# Demands	Topology Type
32LM	32	45	Mesh
45LM	45	45	Mesh
32HM	32	90	Mesh
45HM	45	90	Mesh
32LS	32	45	Star
45LS	45	45	Star
32HS	32	90	Star
45HS	45	90	Star

RESULTS

All testing was performed on a Sun Enterprise 3500 with two 400 MHz UltraSparc processors and 1 GB of RAM. Parallel processing was not utilized. Table 2 illustrates the results obtained within the 12 hour (43200 seconds) testing time limit and shows that GDS generally performed better than CPLEX in terms of objective function, optimality, and time to solution. GDS tended to perform better on the 32 arc problems than on the 45, solving three out of the four to optimality. The percent gap is the ratio of the best solution found to the linear programming relaxation lower bound, where zero percent means the solution is proven optimal.

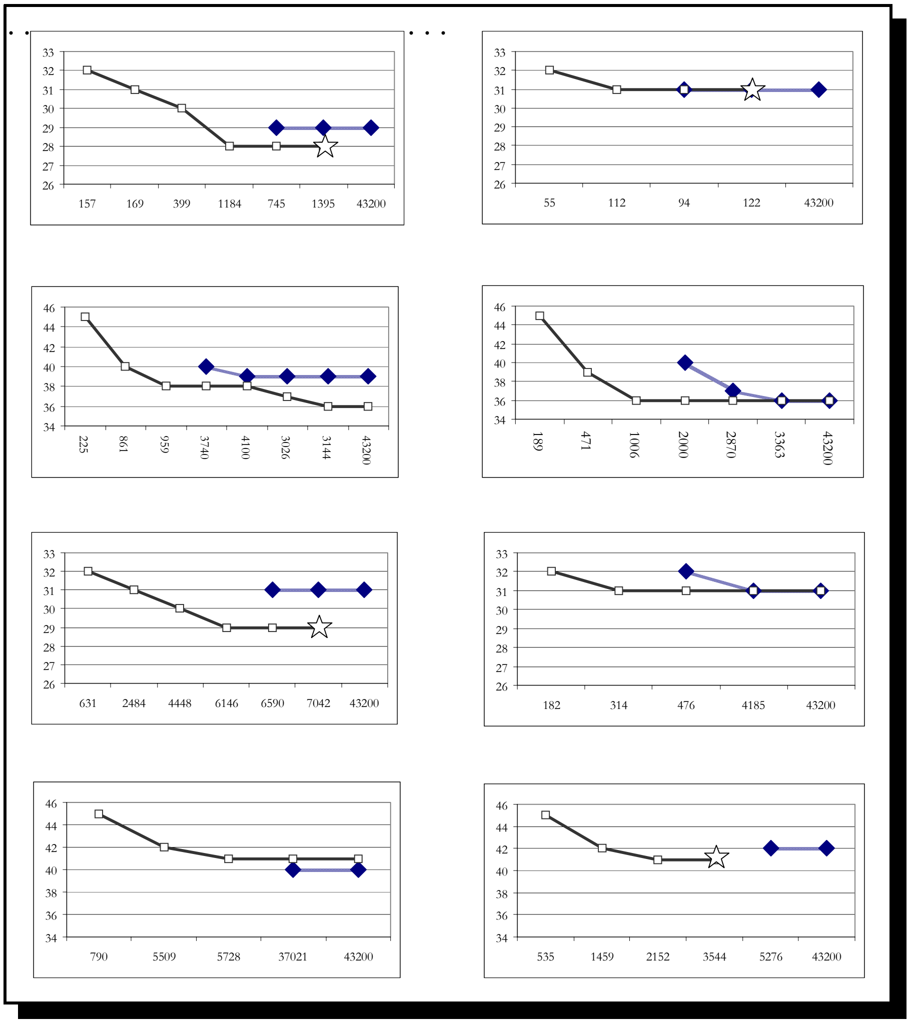
Table 2. Test Set Results

Test ID	Objective Function Value		% Gap		Total Time	
	(1) GDS	(2) CPLEX	(5) GDS	(6) CPLEX	(3) GDS	(4) CPLEX
32LM	5376	5568	0%	66%	1395	43200
45LM	6912	7488	67%	54%	43200	43200
32HM	5568	5952	0%	48%	7042	43200
45HM	7872	7680	74%	66%	43200	43200
32LS	5952	5952	0%	9%	122	43200
45LS	6912	6912	38%	22%	43200	43200
32HS	5952	5952	49%	6%	43200	43200
45HS	7872	7872	0%	30%	3544	43200
Averages	6552	6672	28.5%	37.6%	23113	43200

Figure 2 compares the times for GDS and CPLEX to solve or obtain feasible solutions to the eight problems and shows GDS was faster to the same or better solution. In these figures, the horizontal axis is CPU time in seconds, and the vertical axis is the number of capacitated spans required. The figures also show GDS solving (indicated by the star) four of the problems in about the time it takes CPLEX to find its first feasible solution. The mesh network problems are on the left, the star on the right. Comparing corresponding mesh and star networks, the mesh networks required either the same or less capacity than the star networks.

To investigate the efficacy of GDS on larger problems, two mesh networks having 50 nodes, 95 spans and two demand levels were created (see Table 3). For PR1, GDS performed very well, finding a feasible solution in about an hour and proving optimality in less than 6 hours, while CPLEX took almost two days to find a feasible solution and never proved optimality. For PR2, a feasible solution was found very quickly however CPLEX had not found a feasible solution when processing was halted at 22 days of CPU time. Thus, GDS appears to also perform well as problem complexity increases. Note that GDS spends much more time than CPLEX in preprocessing the problems.

Figure 2. GDS / CPLEX Comparison: Time to Feasible Solutions



Labels: Row 1: 32 arcs / Low Demand / Mesh — 32 arcs / Low Demand / Star
Row 2: 45 arcs / Low Demand / Mesh — 45 arcs / Low Demand / Star
Row 3: 32 arcs / High Demand / Mesh — 32 arcs / High Demand / Star
Row 4: 45 arcs / High Demand / Mesh — 45 arcs / High Demand / Star

Legend:

♦ CPLEX

☐ GDS

☆ Optimality Proven

Table 3. Large Path Restoration Problem Characteristics

Test ID	# demands	# paths	# variables	Preprocessing Time		Time to solution (sec)	
				GDS	CPLEX	GDS	CPLEX
PR1	300	729	6548	3626	187	19076	150568
PR2	200	653	8173	3996	1007	4009	-

CONCLUSIONS

Guided Design Search uses Taguchi methods to efficiently preprocess the joint capacity allocation network design problem in order to obtain estimated effects of decision variables and gain knowledge of the problem structure. Incorporating this knowledge into a commercially available integer programming solver, we improved both solution quality and time to solution for JCA instances. As problem complexity increased, the extra time spent in preprocessing was rewarded with solutions obtained orders of magnitude faster than without GDS integration.

REFERENCES

Abou-Sayed M, Kennington J.L, Nair S. (1997) Joint working and spare capacity assignment in a link restorable mesh network, Department of Computer Science and Engineering, Southern Methodist University, Dallas, TX, Technical Report 96-CSE-16.

Berger PD, Maurer RE. , (2002) *Experimental design with applications in management, engineering, and the sciences*. Duxbury – Thompson Learning.

DeVor R, Chang T, Sutherland J. (1992) *Statistical quality design and control: contemporary concepts and methods*. New York, NY: MacMillan Publishing Company.

Doucette J, Grover W. (2001) Comparison of mesh protection and restoration schemes and the dependency on graph connectivity, presented at the *3rd International Workshop on the Design of Reliable Communication Networks (DRCN),* Budapest, Hungary.

Doucette J, Grover W, Bach T. (2001) Bi-criteria studies of mesh network restoration path-length versus capacity tradeoffs, presented at *OSA Optical Fiber Communications Conference*, Anaheim, California.

Doucette J, Grover W, Martens R. (1999) Modularity and economy-of-scale effects in the optimal design of mesh-restorable networks, *Proceedings of the 1999 IEEE Canadian Conference on Electrical and Computer Engineering*, 226-231.

ILOG Optimization Suite. (2002) ILOG S. A., 9 Rue de Verdun, 94253 Gentilly Cedex, France, and ILOG, Inc., 1080 Linda Vista Ave., Mountain View, California 94043, USA.

Iraschko R, Grover W. (2000) A highly efficient path-restoration protocol for management of optical network transport integrity, *IEEE Journal on Selected Areas in Communications*, 18, 779-794.

Iraschko R, MacGregor M, Grover W. (1998) Optimal capacity placement for path restoration in STM or ATM mesh survivable networks, *IEEE/ACM Transactions on Networking*, 6, 325-336.

Kennington J, Lewis M. (2001) The path restoration version of the spare capacity allocation problem with modularity restrictions: models, algorithms, and an empirical analysis, *INFORMS Journal on Computing*, 13, 181-190.

Lewis MW, Lewis KR, White BJ. (2005) Guided Design Search in the interval bounded sailor assignment problem, to appear *Computers and Operations Research*.

Mason R, Gunst R, Hess J. (1989) *Statistical design and analysis of experiments*. New York, NY: John Wiley and Sons.

Montgomery DC. *Design and analysis of experiments*. (1984) New York, NY: John Wiley and Sons.

Murakami K, Kim H. (1995) Joint optimization of capacity and flow assignment for self-healing ATM networks, in *Proceedings of 1995 IEEE International Conference on Communications*, 216-220.

Taguchi G, Elsayed A, Hsiang T. (1989) *Quality engineering in production systems*. New York: McGraw-Hill.

MANAGERS' PERCEPTIONS OF THE ROLE OF IT IN ORGANIZATIONAL CHANGE

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ABSTRACT

This paper examines the automation environment of public service organizations (PSO) in two different periods to suggest that the introduction of information technology (IT) into public organizations continues to be more pragmatic than strategic. Findings suggest that triggers, such as organizational problems and technological availability for introducing IT are not sufficient to produce substantial organizational change. Furthermore, the results of this study indicate that IT is being introduced into public service organizations by middle-level managers. Managers at these levels seek incremental rather than revolutionary change in their operations. The study suggests that, in order to move from a pragmatic to a new strategic approach, there is a need to establish a partnership between middle managers and those in the strategic apex.

INTRODUCTION: IT ADOPTION IN PUBLIC SERVICE ORGANIZATIONS

Albeit organizations introduce IT for a multitude of reasons, a primary purpose deals with the expectation that IT will streamline information processing, thereby improving organizational performance (Heintze & Bretschneider, 2000; Korac & Kouzmin, 1996; Kraut, et al., 1989; Rice & Contractor, 1990; Drucker, 1988). In deciding on new IT initiatives, organizations follow distinct trajectories and use different criteria sets (Nidumolu et al, 1996). When IT is introduced to improve the timeliness of information flows and to reduce process cycles times, the organization uses a functional approach. Cost-benefit analyses are at the heart of these processes. On the other hand, when the adoption of IT is framed by a political/symbolic approach, decisions are dictated by political, rather than economic considerations. Finally, in a social information processing approach, the adoption of IT is influenced by the perceptions, values, and behaviors of the referential group (Nidumolu et al, 1996).

Public Service Organizations (PSO) differ from their private counterparts in a number of factors, namely, their environments, their organization-environment transactions, and their internal structures and processes (Caudle et al, 1991). While private firms compete in very dynamic markets, public organizations experience an environment less dynamic, more politically driven. PSO do not exhibit a strong market approach and, consequently, there is less incentive for productivity. Their actions are mandated by the government (Tarafdar & Vaidya, 2005; Caudle et al, 1991), and not always market-dictated. They are more strongly influenced by the political, rather than the economic environment. Decision criteria are more complex in PSO, and structures and process more rigid (Heintze & Bretschneider, 2000). Managers tend to play a more political role and have less decision-making autonomy (Heintze & Bretschneider, 2000). Granted that social accountability is strongly emphasized in PSO, and that decisions are strongly influenced by political forces outside the organization (Heintze & Bretschneider, 2000), decision-making processes tend to be centralized and more formalized.

Market-driven firms and PSO also differ in their approaches to IT adoption and use. PSO are more information intense than private firms (Heintze & Bretschneider, 2000), and their information requirements are more difficult and unstable. Whereas private firms treat IT as proprietary, for use as a competitive advantage, PSO emphasize the sharing of applications and technical assistance (Caudle, 1991). Furthermore, while senior managers in the private sector have decision power regarding new IT initiatives (Heintze & Bretschneider, 2000), there is evidence that middle managers play a critical role in driving IT implementations in PSO (Heintze & Bretschneider, 2000; Pinnsoneault & Kraemer, 2002; Caudle, 1991). IT decisions in private firms are driven by strategic considerations. PSO undertake IT projects as a response to government mandates (Tarafdar & Vaidya, 2005). Finally, in highly centralized structures, such as most PSO, middle managers' role focuses on information handling and routine decision-making, rather than less routine work (Pinnsoneault & Kraemer, 2002)

RESEARCH FRAMEWORK

This research examines the automation environment in PSO in two different eras. The first phase of this study was conducted at a time when computing activities were changing from a mainframe-based environment to a distributed environment, in early 1990's. By that time, organizations were entering a second wave of IT-enabled organizational change, in which they were moving from data processing to data production and application. The second phase was administered twelve years later, in 2004, in a time when most IT adoption processes were mediated by strategic considerations. The aim had become one of supporting organizational learning, by enabling an environment conducive to managing effectively the knowledge accumulated by the firm.

The first phase of the study used a field survey to collect data and was based on a total of 140 IT projects that were introduced in agencies delivering services in the New York metropolitan area, such as social, law enforcement, community development, and capital project services. Data were collected during 1992 and 1993. Although the sample size was large enough, it doesn't represent the entire spectrum of IT projects in the public sector. The second phase was based on a smaller sample of interviews; however, the diversity of the projects was similar to those in the initial phase. The second phase of the study used 30 semi-structured interviews with middle managers from various public service organizations. All managers interviewed have been involved with IT efforts (as users and being an integral part of the implementation processes) for more than ten years.

This research design represents a common form of ex-post facto analysis that seeks to explore relationships between variables. The questionnaire used in the first phase was self-administered in a report format, in which managers answered open-ended questions regarding IT projects implemented in their departments. They were asked to describe the objectives, the problems they intended to solve, and the technological solutions that were adopted. For each project managers described the following: the organizational context and problems, the intervention or managers' response to the problems, the benefits that resulted from the introduction of IT, and the potential for marketing the project to other PSO. The follow-up interviews used an abridged version of the survey, focusing on the same four themes, and asked managers to discuss and comment on the same set of factors.

In summary, this study uses managers' perception to analyze the organizational problems management intended to solve with the introduction of IT, and explores the decision-making levels supported by the adopted IT. Put it differently, this study attempts to provide answers to the following questions: a) what are the objectives managers indicate act as triggers for the introduction of IT, b) what are the organizational problems that managers seek to solve through the introduction of IT, and c) what are the decisions level mostly affected by the introduction of IT in these organizations? The following three sections analyze data from the first phase of the study to provide insights regarding these three questions. The fourth section provides insights regarding the currant IT environment. The final section provides summary and conclusions.

OBJECTIVES BEHIND THE INTRODUCTION OF IT: MANAGERIAL JUSTIFICATIONS

Table 1 includes a sample of managers' statements describing the intentions behind their decisions. These statements provide insight into the goals managers had tried to attain by introducing IT in their units. Apparently, the introduction of IT did not respond directly to specific organizational problems, but was instead guided by a motivation to seize technology-enabled opportunities. An organizational-outcome taxonomy can be mapped on top of these clusters (Watad, 2000). While the first three clusters are associated to outcome factors such as productivity, competitive advantages, responsiveness, and accountability, the fourth is linked to a task-execution and control factor. The fifth cluster corresponds to structural issues and re-engineering efforts. The final two clusters relate to analytical skills, knowledge management, and organizational memory factors, all indicators of managerial efforts to enhance organizational learning.

Table 1: Reasons to Introduce IT
"To automate and to replace old technology"; "to improve the existing system"; "to improve accuracy in analysis"; "to reduce repetitive efforts".
"To improve management and allocation of resources, to share resources"; "to improve quality of products and services".
"To deliver services effectively"; "to improve responsiveness"; "to provide timely information, and to mobilize public awareness"; "to improve safety".
"To track status of transactions, and monitor activities"; "to enhance compliance, and improve control over tasks and operations";
"To redesign processes"; "to eliminate stages in the operation"; "to improve work flow". "To improve communication", "to standardize responses", "to coordinate processes", "to decentralize operations", "to centralize responsibility".
"To improve presentation of results through the use of graphical software packages"; "to improve data analysis"." To develop flexible systems that enhance functionality and the capacity for ad-hoc report generation"; "to improve access to and facilitate links with information sources, and to improve flexibility in providing information".
"To improve information management"; "to develop historical databases and improve the organizational ability to collect and manage information"; "to monitor large amounts of data"; "to develop a comprehensive system to integrate data".

PROBLEMS SOLVED WITH THE INTRODUCTION OF IT: MANAGERIAL POST-FACTO RATIONALIZATION

A two-tier process was used to identify organizational problems that managers attempted to solve by introducing IT. A categorization of problem types was first developed, and then used as part of a deductive analysis to classify all responses. This deductive process included four steps, namely: (i) identifying and listing problem statements in the written reports, (ii) clustering statements into meaningful categories based on the literature, (iii) constructing final categories, and (iv) classifying projects according to these categories. Sixty different problem statements from 140 projects were identified. They were carefully reviewed and then clustered into seven mutually exclusive categories. A second expert, who is an academic with IT background, also reviewed the cases. The inter-judges level of reliability was 86%. Table 2 displays these categories as well as their frequencies.

Table 2: IT Adoption Triggers: Categories of Problems

Category	Types of Problems	Frequency
Manual Processing	Manual calculation, search, and verification of time, labor, and financial transactions. Three subgroups: *Accuracy problems:* data errors, redundancy or double record keeping, and inaccurate transactions. *Speed problems:* delays in processing and report generation, time consuming operations, slow production line, and inefficient transactions. *Cost problems:* time-intensive operations, labor-intensive operations, and costly operations. Managers' who identified manual problems wanted to reduce costs and streamline operations.	74%
Capacity	Large volumes, increases in demand, increase in workload and backlog, use of large amounts of paper work and manpower, and increasing scope of work and/or decrease in resources. Managers sought to solve these problems by sharing resources and integrating activities through the use of IT.	23%
Control	Limited ability to track work (e.g., tracking violations), fragmentation of control, poor enforcement of regulations, lack of coordination, limited ability to control work, and lack of centralized control. Managers sought to solve control problems mainly through the streamlining of operations and the automation of existing procedures.	21%
Information Access and Management	*Access problems:* information that is not readily available to users, lack of access to data stored in either mainframe systems or external databases, and lack of compatibility. *Information processing problems:* lack of information, out-dated information, and inability to handle extensive use of information, limited reporting capabilities, and fragmentation in related information, poorly organized data, and the unavailability of information in an easily understood format.	16%
Operational	Complex processes, fragmented organizational operations, and difficult tasks.	14%
Service Quality and Responsiveness	Limited ability to deliver services or to reach out; poor responsiveness, or lack of a standard response; regulation; poor enforcement, lack of accountability, lack of security, lack of compliance, and fragmented responsibility.	13%
Other	Lack of time, misuse of time, old equipment, lack of skilled staff, misuse of space, and lack of vendor support; existing systems that are inflexible, not user friendly, still required manual work, and produce rigid output. The managers' response was to upgrade these systems by redesigning them and installing new technology.	11%

The above-mentioned seven categories of triggers for IT adoption are what managers say they did rather than what actually happened. One can argue that they represent post-facto rationalizations of actions taken (Knights & Maurray, 1994), Being this so, there seems to be a gap between actual objectives and perceived problems, as well as between plans and actions (Goodman and Burke, 1982). Regardless of whether the triggers were deemed as objectives, problems, or post-facto rationalizations, they determined the attention structure of public managers regarding the use of IT. In addition to reflecting what managers perceive can be achieved or can be solved with the introduction of IT, this classification of triggers provides an insight into the automation environment and the prevalent IT culture in PSO. Managers' perceptions (Weick, 1969) are important because they affect managers' decision-making and actions regarding the introduction of IT into their organizations (Heintze & Bretschneider, 2000).

An in-depth analysis of the sets of triggers indicates that the introduction and use of IT in these PSO occurred as a result of the interaction of two opposing forces, which intertwined in the context of technological availability and managerial actions (Markus and Robey, 1988). They are the technological push and the organizational pull. The technological push is characterized by managers' desire to take advantage of IT capabilities to improve information access and management processes, enhance resource allocation, and simplify operations. On the other hand, the organizational pull is characterized by a desire to solve structural problems and boost organizational performance and control. Improving the quality of products and services, for instance, can be interpreted as a technology-led project, whereas reducing delay in delivering services can be interpreted as an organization-led project. Albeit IT is the driving force in the former case, organizational variables are the catalyst in the latter.

IT IMPACTS ON DECISION LEVEL

The nature of the changes that were enabled by the introduction of IT was explored also by analyzing the "decision level" at which projects were aimed to provide support. An analysis of the decision level in the sample analyzed exposes the managerial locus of decision support intended with the automation efforts.

Level of decision-support refers to whether the decision level at which IT is introduced is strategic (i.e., unstructured decisions), tactical (i.e., semi-structured decisions), or operational (i.e., structured decisions). In the Human Resource Administration agency, for instance, projects related to activities such as placement data, employee evaluation, payroll data, employee history data, and position inventory, mostly support structured decisions at the operational level. On the other hand, projects related to job analysis and design, skills inventory, recruiting, compensation and benefits, and training and development provide support to projects where semi-structured decision are the locus of attention. Finally, projects that revolve around tasks such as staffing, planning, and labor negotiations generally support decisions at the strategic level.

Using data drawn from the survey, the whole set of projects was classified, based on the level at which they were expected to provide support. Table 3 displays the frequency distribution of the projects according to the level of "decision support".

Table 3: IT projects by Level of Decision Support		
Level of Support	Frequency	Percentage
Strategic	15	11%
Tactical	25	18%
Operational	100	71%

Apparently, most projects were introduced to support decisions primarily at the operational level. This finding, which suggests that technology is mainly introduced by middle and front level-managers, is in agreement with a traditional view of organizations where information flows bottom-up and decisions top-down. The low level of activity at the strategic level may imply that the traditional split between strategic and tactical/operational levels still exists for the PSO studied, and that information processing takes place at both the operational and tactical levels.

This phenomenon was particularly evident in two units of an organization that operated separately under the existing organizational structure, with each one having its own management hierarchy. After examining their business needs for automation, it was recommended that it would be more effective for both units to merge. The idea of merging the units was introduced to the senior managers in the hope that an appropriate solution could be adopted. However, these managers were reluctant to deal with the situation. One possible explanation for their stance is that the merge would force management to give up personnel (i.e., reduce their budget), and would lead to a political struggle between units' heads. This example illustrates the reluctance of senior managers to see the introduction of IT in a strategic way. To compound this problem further, many top managers in PSO are hired from outside, and by the time they become familiar with their jobs and the organizational issues they have to deal with, they are ready to move to a new position (Williamson, 1996).

THE CURRENT IT ENVIRONMENT OF IT ADOPTION

The second phase of the study was conducted in 2004. In the new era IT adoptions are framed in a strategic context in terms of providing competitive advantage, accountability, and responsiveness. IT is being introduced also to support e-business at all levels of organizations. Thus, this study expected to find a shift in the approach PSO used to introduce new IT, and a different locus of support for those new technologies. Although the sample size was smaller in the second phase, it was sufficient to provide understanding of whether changes have taken place in recent years in PSO.

The data collected in this phase suggested that there was a change in the structure of the portfolio of problems managers attempted to solve with the introduction of IT. Although *Manual Processing* problems were still a substantial portion of their portfolio, they were not as prevalent as in the first phase. Their frequency dropped from 74% to 50% (see Table 4). On the other hand, *Information Access and Management* problems emerged to be the most prevalent trigger for IT adoption and were the main focus of managers' attention and efforts. Their frequency grew from 16% up to 60%.

Table 4: The Second Phase - IT Adoption Triggers: Categories of Problems

Category of Problems	Frequency
Manual Processing	50%
Capacity	23%
Control	21%
Information Access and Management	60%
Operational	14%
Service Quality and Responsiveness	13%
Other	11%

In terms of the locus of action, there were very little changes reported in the interviews. The frequency distribution remained unchanged, with approximately 70% of the efforts at the operational level, around 20% at the tactical level, and close to 10% at the strategic level. In other words, the bulk of projects reported were still aimed at providing support at the tactical and operational levels, while the strategic level seemed to be not a priority for the introduction of IT in PSO. It appears that middle managers are still spearheading the IT initiatives in their units, and that their focus remains unaffected. Middle managers seem to have different IT priorities than those of senior executives (Heintze & Bretschneider, 2000). In addition, where middle managers have more control over the use of IT, they select the type of IT that is akin to their roles and priorities (Pinnsoneault & Kraemer, 2002).

Drawing on these results, there are strong arguments to motivate senior managers to get involved in the introduction of IT. For instance, the approach middle managers use to adopt IT is based on the need to solve immediate problems as they occur, and to reinforce their roles (Pinnsoneault & Kraemer, 2002). For the most part, they automate existing procedures without examining the validity of re-engineering them. Additionally, they are often forced to duplicate existing procedures to ensure more accountability, given the bureaucratic approach that is pervasive to public management (Heintze & Bretschneider, 2000). Furthermore, as information usually flows bottom-up, mid-level managers have the means to obstruct its flow to top managers, and they may impede the information flow to senior managers. They may fear losing their position and/or reducing their control over organizational resources. Therefore, a partnership and mutual understanding between the two levels of management will help make the introduction of IT more strategic.

CONCLUSIONS

This paper examined the automation environment of public service organizations (PSO) in a period of twelve years. The results of this study coincide with reports in the general literature stating that managers invest in information technologies (IT) to achieve pragmatic ends, such as lowering the cost and time needed in producing and delivering the goods and services for which they are responsible (Pinnsoneault & Kraemer, 2002; Richter, 1996; Brudney & Selden, 1995; Grady & Chi, 1994; Browning, 1990; ICMA, 1989; Danziger & Kraemer, 1988), and to respond to external political forces that dictate IT adoption practices (Tarafdar & Vaidya, 2005; Heintze & Bretschneider, 2000).

The main conclusion of the study is that, in spite of the prevalent shift in focus from a productivity emphasis to a more strategic outlook, the introduction and use of IT in PSOs takes place mainly at the operational level. Furthermore, IT efforts are spearheaded by middle, rather than senior managers. Public managers are still more concerned with automating the operating core functions, than advancing the strategy of their organizations. They are inclined to adopt IT to support their roles, rather than strategically transform the organization. Most of the automation activities are still largely aimed at supporting decision-making at the operational level. The automation efforts in PSO are, even today, being shaped by decisions made at both the middle management level in the operating core, and the operational level of these PSO. There seems to be a lack of strategic focus in IT projects. Consequently, organizational change tends to be more incremental than revolutionary

These findings lead to questions as to why PSO managers use such an approach: is it because they want to protect their jobs and are not willing to take risks; or because organizational constraints prevent effective introduction of IT into public organizations, or they lack knowledge to radically change the organization? One direct proposition or explanation could be that middle managers do not see IT as a strategic asset but only as an operational and role-reinforcement tool. Another proposition is that managers are failing to see the whole picture of their organizations and consequently are not able to solve organizational problems strategically. The study suggests that, in order to move from a pragmatic to a new systemic approach, there is a need to establish a new mechanism of coordination between middle and top managers. Hopefully, this type of partnership between the middle- and top-level management will expedite the transformation of the pragmatic IT environment into a new strategic one.

REFERENCES

Browning, J. (1990). The Ubiquitous Machine. *The Economist*, June 16, 7-20.

Brudney, J. & S. Selden (1995). The adoption of innovation by smaller local governments: The case of computer technology. *American Review of Public Administration*, 25(1), 71-86

Caudle, S.R., W.L. Gorr, & K.E. Newcomer (1991) Key Information Systems Management Issues for the Public Sector. *MIS Quarterly*, 15(2), 171-188

Danziger, J.N. & K. Kraemer (1986). People and Computers: *The Impact of Computers on End Users in Organizations.* NY: Columbia University Press.

Drucker, P.F. (1988). The Coming of the New Organization. *Harvard Business Review*, January-February.

Goodman, P. & L. Burke (1982). Studies of Change in Organizations: A Status Report. In Goodman and Associates (Eds.), *Change in Organizations: New Perspectives in Theory, Research, and Practice*. San Francisco, CA: Jossey-Bass.

Grady, D. & K. Chi, K. (1994). Formulating and implementing public sector innovations: The political environment of state government innovator. *Public Administration Quarterly*, 17(4), 468-484.

Heintze, T. & S. Bretschneider (2000). Information Technology and Restructuring in Public Organizations: Does Adoption Affect Organizational Structures, Communications, and Decision Making? *Journal of Public Administration Research & Theory*, 10(4), 801-830

ICMA, (1989). *Baseline Data Report, Vol. 21, No. 1*. International City Management Association, Washington D.C.

Korac-Kakabadsen & A Kouzmin (1996). Molecular Innovation and Molar Scanning Strategies for the Adoption of New Information Technology (IT). *Public Productivity & Management Review*, 19(4), 422-433.

Knights & Maurray, (1994). *Managers Divided: Organization Politics and Information Technology Management*. Chichester, UK: Wiley

Markus, M.L. & D. Robey D. (1988) Information Technology and Organizational Change: Causal Structure in Theory and Research. *Management Science*, 34(5.)

Mintzberg H. (1979). *The Structuring of Organizations*. Englewood Cliffs, NJ: Prentice-Hall.

Nidumolu, S.R., S.E. Goodman, D.R. Vogel & A.K. Danowitz (1996) Information Technology for Local Administration Support: The Governorates Project in Egypt. *MIS Quarterly*, 20(2), 197-224

Pinnsoneault, A. & K.L. Kraemer (2002). Exploring the Role of Information Technology in Organizational Downsizing: A Tale of Two American Cities. *Organization Science*, 13(2), 191-208

Rice, R.E. & N.S. Contractor. (1990). Conceptualizing Effects of Office Information Systems: A Methodology and Application for the Study of Alpha, Beta, and Gamma Changes. *Decision Sciences*, 21, 301-317.

Richter, M. (1996). Technology acquisition and implementation: Learning the hard way. *Government Finance Review*, 12(1), 7-11.

Tarafdar M. & S.D. Vaidya (2005). Adoption and Implementation of IT in Developing Nations: Experiences from Two Public Sector Enterprises in India. *Journal of Cases on Information Technology*, 7(1), 111-135

Watad, M. (2000). Information Systems Assessment in Public Service Organizations. *International Journal of Services Technology and Management* Vol. 1, No. 4.

Weick, K.E. (1969). *The Social Psychology of Organizing*. Reading, Mass.: Addison Wesley.

Williamson, M. (1996). Rethinking the way government works. *CIO*, 9(18), 36-48.

DEVELOPMENT OF WEB-BASED DECISION SUPPORT SYSTEM FOR BUSINESS PROCESS REENGINEERING IN A HEALTH-CARE SYSTEM

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ABSTRACT

A web-based decision support system (DSS) can provide management with a strategic plan for business process reengineering (BPR) in a health-care system. An attempt is made to develop a DSS for designing, evaluating, and implementing a strategic plan for BPR. A model is developed and analyzed to simulate a real hospital setting. Goal criteria and priorities are identified and established. The model results are evaluated and discussions are made along with web application in order to enhance the model applicability. The model provides the management with valuable information for planning and controlling hospital e-business activities.

INTRODUCTION

As the dynamics of the demanding marketplace and the requirement of competitive advantage have transformed, the need for decision support system (DSS) models for process reengineering in the health-care e-business system has been emphasized. Successful linkages of these planning processes play a critical role affecting business performance (Ackerman, Wall & Borman, 1999; Aldowaisan and Gaafar, 1999; Sheng, 2002; Short and Venkatraman, 1992; and Teng, Grover and Fiedler, 1996). Factors affecting business performance in a health-care e-business system are widely identified. Financial and non-financial factors should be considered together in the health-care decision process. The health-care e-business strategy needs to be based on compromise among the diverse stakeholders in the health-care system. Among DSS types, a model-driven DSS emphasizes access and control of a model that uses data and parameters provided by decision-makers to support them in analyzing a real-world e-business situation.

Due to the web technology and organizational paradigm shift, business operations in health-care e-business systems may become more tightly coupled with primary business processes such as admissions, capacity, financing, manpower, and revenue planning. Web technology can deliver unprecedented opportunities to reengineer the business processes in health-care systems. Web technology is considered an emerging area for DSS and an important tool for DSS development. Web technology can enrich model-driven DSS. Web-based DSS has the advantages of reducing current technological obstacles of computerized systems, because of better sharing in decision information, and making more efficient decisions with less cost for model implementation (Courtney, 2001; Rao & Turoff, 2000; and Shim et al., 2002).

Strategic business process reengineering (BPR) in a health-care environment is a growing requirement for improving profitability and productivity. Subjective decision-making processes can be very critical in the multiple and complicated problems with trade-off relationships. When management considers several conflicting goals to achieve, a DSS model enables effective results in business processes and other operational environments in health-care e-business system (Sarker & Lee, 1999; and Stoddard & Jarvenpaa, 1995). However, previous DSS studies have rarely explored to develop an integrated model based DSS dealing with comprehensive core functions in health-care e-business system. Thus, an appropriate model development is essential to create a long-term opportunity for BPR in a health-care e-business system.

The purposes of this paper are (1) to develop a DSS model that aims at designing, evaluating, and implementing a strategic plan for BPR in a health-care system, and (2) to provide management with an insight on a web-enabled DSS model that can enhance business performance and refine operational strategy in health-care e-business activities.

Section 2 reviews a brief literature of decision support systems and business process reengineering. Section 3 presents a problem background with data modeling and goal decomposition. Section 4 presents model development dealing with decision variables, constraints and model formulation. Section 5 provides the developed model solution and discussion, followed by a conclusion.

LITERATURE REVIEW

Decision Support System

Decision support system (DSS) is an intelligent model dealing with semi- or ill-defined and structured decision-making problems in order to support better judgment amongst decision-makers. The concept of DSS has been defined as a system using management activities and decision-making types (Gory & Morton, 1971). Decision-making process stages in DSS consist of four stages: intelligence stage for recognizing appropriate problems in management environment, formulation stage for developing possible alternatives, choice stage for selecting a satisfying solution among potential alternatives, and implementation stage for analyzing and evaluating solutions with sensitivity analysis.

Information needs in DSS environment are characterized as requiring different types of information systems and technologies (Min, 1998). DSS has following characteristics: it is designed specifically for facilitating decision-making process and planning process; it is responded promptly for fulfilling decision-makers needs in short and long term; and it is supported intelligently for making better decision. With this context, DSS research has focused on four directions: intelligent computer system, model application, problem-solving model, and user-interface system. DSS applications have extended to collaborative DSS, negotiate DSS, knowledge-based DSS, and web-based DSS.

Web-based DSS is defined as a system that communicates decision support information or tools to decision-makers through a web environment. Web-based DSS is a DSS using web technology in order to provide decision-makers with business information through internets, extranets and intranets. The web technology is considered as an emerging area for development of DSS. Web-based DSS has advantages of reducing current technological obstacles of computerized systems, because of better sharing in decision information, and making more efficient decisions with less cost for model implementation.

DSS in health services sector has steadily appeared in the literature due to the quality of care, information technology, and financial significance (Collen, 1999; and Miller, 1994). Effective decision support systems in health-care systems rely on accurate patient data and health information, efficient decision-making models, and standardized data production mechanisms. Several issues in health-care decision support areas have changed the current research paradigm. Health-care DSS have recently focused on admissions planning (De Veries & Beekman, 1998; and Kurster & Groot, 1996), health-care financing (Mosmans, Praet & Dumont, 2002), information management (Lee & Kwak, 1999), information technology (Forgionne & Kohli, 1996), knowledge management (Pederson & Larsen, 2001), medical diagnosis (Mangiameli, West & Rampal, 2004); patient relationship (Kohli et al., 2001), and resource allocation (Vissers, 1998).

BUSINESS PROCESS REENGINEERING

Business process reengineering (BPR) is defined as fundamental rethinking and innovative redesign of business processes to achieve a dramatic improvement in critical and core measures of performance, such as cost, quality, speed, flexibility, and value-added service. Business process itself is a management philosophy or strategy that considers a collection of management activities taking input resources and deriving valuable outputs for a customer.

BPR characteristics take various forms. There are four types of characteristics based on scope and scale: functional integration, functional refinement, business redefinition, and process redesign. The efforts of BPR focus on (1) getting users of the outcome of the process, (2) merging information-processing into the origin of information production, (3) treating geographically dispersed resources, (4) linking parallel activities, (5) putting the decision point into the process, and (6) capturing necessary information when needed. The goals in BPR decisions are conflicting due to the existence of different goals in each sub-unit. It is difficult to meet current needs of multi-dimensional sub-units unless a systematic approach to evaluate potential future BPR decisions is undertaken (Davenport & Short, 1990; and Kettinger, Teng & Guha, 1997).

Many BPR issues in a health-care system have appeared in recent literature (Corlett, Maher & Sidman, 1998; Grimson, 2001; and Li, Benton & Leong, 2002). Efforts of BPR in a health-care system are called for within the organization. Most researchers and practitioners agree that BPR success relies on mission, leadership, new investments, process reengineering, resource allocation, and strategic alliance (Ho, Chan & Kidwell, 1999; Kohn, 1994; Newman, 1997; and Seymour & Guillett, 1997).

PROBLEM STATEMENT

Data Collection

The health-care system in this study is a comprehensive hospital, a leading patient-oriented provider of health services. The hospital's goal is to provide high quality and cost-effective health services while enriching a catholic-affiliated organization's mission. The organization has five different independent health-care systems located at different areas. The organization has built a web system with intelligent functions in supporting hospital e-business activities through web-based order communication system (OCS). Top decision-makers from the hospital and a consulting firm have participated in the overall review process. The related goals and criteria are justifies by the task force team. Data templates pertinent to the strategic proposal are derived. The task force team is responsible for all validated data sets from the hospital, examines the data, and acknowledges the validation for the collected data set. Based on the data set, an initial proposal of the DSS model development for process reengineering is established. Some data utilized in this study had been modified slightly to meet a software system requirement, even though the modified data have not distorted the original justification of input data.

The management wants to provide better services for patients in the health-care organization. Among 17 departments in the hospital, OB/GYN/pediatrics departments, five surgery departments, and an internal medicine department are selected for this study since they are the most core areas in the hospital. Characteristics of patients are divided by residency status (resident in the city or non-resident in the city) and visit type (first visits or revisits). Identifying these characteristics is very important to estimate the potential profitability of the hospital. Three major divisions have an admissions goal as well as hospital admissions status and system utilization rate.

GOAL JUSTIFICATION

Establishing goal decomposition and prioritization is completed for the proposed decision support model development. Synthesized priority is calculated for each goal in order to obtain the overall relative importance of the five goals using an expert opinion (Saaty, 1980).

Based on the above data, the goal priorities and the relevant information about business process redesign are established as follows: priority 1 (P_1) - financial goal (G_3), priority 2 (P_2) - manpower goal (G_4), priority 3 (P_3) -revenue goal (G_5), priority 4 (P_4) - capacity goal (G_2) and priority 5 (P_5) - admissions goal (G_1).

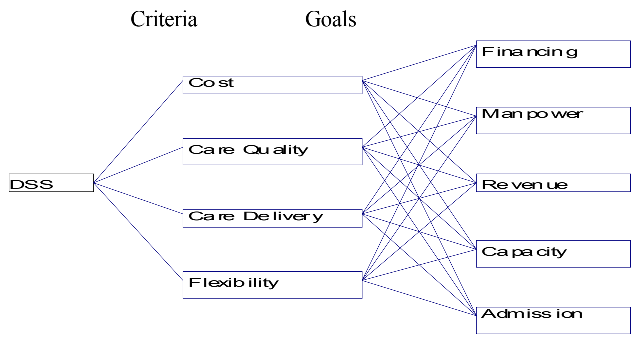

Figure 1. Criteria and Goal Decomposition

There are sub-goals under five major goals. Financing planning goal has two sub-goals: service expenditure goal (P_{11}) and information facility goal (P_{12}). Manpower planning goal have two sub-goals: manpower utilization (P_{21}) and payroll increase agreement (P_{22}). Revenue planning goal has two sub-goals: total revenue increase (P_{31}) and profitability fulfillment (P_{32}). Capacity planning goal have three sub-goals: accommodation (P_{41}), hospital utilization (P_{42}), and hospital admission (P_{43}). Admission planning goal has three goals: residential patient admission (P_{51}), non-residential patient admission (P_{52}), and revisit patient admission (P_{53}). These sub-goals are prioritized based on internal agreements. Decision-makers such as the hospital president, a chief information officer (CIO), a medical unit director, and a financial unit director have justified the synthesized prioritization of the overall goals for the business process in the health-care organization under consideration.

MODEL DEVELOPMENT

Decision Variables

DSS models in business process reengineering have generally been limited to addressing financial goals, rather than other strategic policies of an organization. In this paper, a DSS model is formulated based on the following information. There are five different types of decision variables embracing 24 decision variables.

X^a_{ij} = admissions level in patient group i (i = 1, 2, 3, and 4) and department j (j=1,2, and 3)
X^f_i = financing level for services expenditure (i=1) and for information facilities (i=2)

X^m_i = manpower level in different types of work i (i = 1, 2,...,6)
X^p_i = payroll level in different types of work i (i = 1, 2,...,6)
X^r_i = revenue level in different types of work i (i = 1, 2,...,6)
where X^a_{ij}, $X^f_{i,}$ X^m_i, X^p_i, and X^r_i ³ 0

X^a is number of admission in patient group i: first-visit resident (i=1), re-visit resident (i=2), first-visit non-resident (i=3), and re-visit non-resident (i=4); department j: OB/GYN/ pediatrics (j=1), surgery (j=2), and internal medicine (j=3). X^m is number of manpower in physician (i=1), nurse (i=2), technician I (i=3), technician II (i=4), management I (i=5), and management II (i=6). X^p and X^r are payroll amounts and revenue amounts in physician (i=1), nurse (i=2), technician I (i=3), technician II (i=4), management I (i=5), and management II (i=6).

Systems Constraints

There are two different types of constraints: system constraints and goal constraints. System constraints (1-3): First-visit resident patient cannot exceed the maximum level of accommodation in each patient group of in OB/GYN/pediatrics (1,800 patients), surgery (900 patients), and internal medicine (850 patients). System constraints (4-6): Re-visit resident patient cannot exceed the maximum level of accommodation in each patient group of in OB/GYN/pediatrics (5,700 patients), surgery (1,900 patients), and internal medicine (2,100 patients).System constraints (7-9): First-visit non-resident patient cannot exceed the maximum level of accommodation in each patient group of in OB/GYN/pediatrics (1,500 patients), surgery (400 patients), and internal medicine (550 patients). System constraints (10-12): Re-visit non-resident patient cannot exceed the maximum level of accommodation in each patient group of in OB/GYN/pediatrics (2,500 patients), surgery (800 patients), and internal medicine (1,200 patients).

Goal Constraints

Financial Planning Goal Constraints have two sub-goals. Goal constraint (13) of sub-goal (P_{11}) -Prepare proper funds for service expenditure ($2,5200,000). Goal constraint (14) of sub-goal (P_{12}) - Supply an appropriate budget for information facilities ($2,088,000).

Manpower Planning Goal Constraints have two sub-goals. Goal constraints (15-20) of sub-goal (P_{21}) - Meet effective utilization of the required human resource level of physician group (37 persons), nurse group (166 persons), technician I (10 persons), technician II (39 persons), management I (53 persons), and management II (13 persons). Goal constraints (21-26) of sub-goal (P_{22}) - Achieve the payroll increase agreement by certain percentage points required from the current salary level of physician group ($53,860,000), nurse group ($11,090,000), technician I ($18,070,000), technician II ($13,30,000), management I ($13,250,000), and management II ($14,300,000).

Revenue Planning Goal Constraints have two sub-goals. Goal constraint (27) of sub-goal (P_{31}) - Do not allow an over-achievement of total revenue increase ($ 2,860,000) from the current level in terms of patient satisfaction. Goal constraint (28) of sub-goal (P_{32}) - Achieve the expected profitability level ($80,000) that is the difference between the expected revenue increase amount and the expected expenditure increase amount.

Capacity Planning Goal Constraints have three sub-goals. Goal constraint (29) of sub-goal (P_{41}) - Minimize the under-achievement of the accommodation goal of patients (1,380 persons) that is the sum of three divisions based on the residential status and patient type: capacity utilization percentage with first visit and resident (70%), revisit and resident (80%), first visit and non-resident (40%), revisit and non-resident (50%). Goal constraints (30-32) of sub-goal (P_{42}) - Meet the hospital resource utilization capacity to handle total admissions of 9,000 in OB/GYN/pediatrics, 3,500 in surgery, and 4,000 in internal medicine. Goal constraint (33) of sub-goal (P_{43}) - Meet the hospital admissions goal of 15,000 new patients in three divisions.

Admission Planning Goal Constraints have three sub-goals. Goal constraint (34) of sub-goal (P_{51}) - Minimize the under-achievement of the targeted admission with 70% of hospital admission capacity for residential patients. Goal constraint (35) of sub-goal (P_{52}) - Minimize the over-achievement of the targeted admission with 30% of hospital admission capacity for non-residential patients. Goal constraint (36) of sub-goal (P_{53}) - Meet the targeted goal with 60% of hospital admission capacity for revisit patients.

MODEL FORMULATION

DSS for BPR in the health-care system is to minimize the value of the objective function subject to goal constraints (13)-(36), satisfying the preemptive priority rules, as shown in Table 1.

MODEL ANALYSIS AND DISCUSSION

Model Analysis

In this DSS model, a non-dominated solution has been sought. A non-dominated solution is defined in the following manner: a feasible solution to a multicriteria decision-making problem is non-inferior, if no other feasible solutions derive an improvement in one objective, without creating a trade-off in another objective. Regardless of the weighting structures and the goals, this model can lead to inferior, sub-optimal solutions. These solutions are not necessarily the optimal ones available to the decision-maker. Therefore, it is called a satisfying solution. Opportunity costs are given as well as the increases and decreases in the values of the coefficients and the right-hand-side elements. Management can determine in advance what will happen if the outcome deviates from overall objectives. In the example given, management can use the information from the solutions to alter their decision variables as any plan can come up with the new satisfying solution.

Table 1. Modeling for BPR in Health-Care System

$$\text{Min } Z = P_{11} d^-_1 + P_{12} d^+_2 + P_{21} \sum_{i=3}^{8} (d^-_i + d^+_i) + P_{22} \sum_{i=9}^{14} (d^-_i + d^+_i) + P_{31} d^+_{15} + P_{32} (d^-_{16} + d^+_{16}) + P_{41} d^-_{17} + P_{42} \sum_{i=18}^{20} (d^-_i + d^+_i) + P_{43} (d^-_{21} + d^+_{21}) + P_{51} d^-_{22} + P_{52} d^+_{23} + P_{53} (d^-_{24} + d^+_{24})$$

Subject to	
X^a_{11} £ 1800	(1)
X^a_{12} £ 900	(2)
X^a_{13} £ 850	(3)
X^a_{21} £ 5700	(4)
X^a_{22} £ 1900	(5)
X^a_{23}£ 2100	(6)
X^a_{31} £ 1500	(7)
X^a_{32} £ 400	(8)
X^a_{33} £ 550	(9)
X^a_{41} £ 2500	(10)
X^a_{42} £ 800	(11)
X^a_{43} £ 1200	(12)
$X^f_1 + d^-_1 - d^+_1 = 2520$	(13)
$X^f_2 + d^-_2 - d^+_2 = 2088$	(14)
$X^m_1 + d^-_3 - d^+_3 = 37$	(15)
$X^m_2 + d^-_4 - d^+_4 = 166$	(16)
$X^m_3 + d^-_5 - d^+_5 = 10$	(17)
$X^m_4 + d^-_6 - d^+_6 = 39$	(18)
$X^m_5 + d^-_7 - d^+_7 = 53$	(19)
$X^m_6 + d^-_8 - d^+_8 = 13$	(20)
$X^P_1 + d^-_9 - d^+_9 = 59{,}400$	(21)
$X^P_2 + d^-_{10} - d^+_{10} = 13{,}200$	(22)
$X^P_3 + d^-_{11} - d^+_{11} = 19{,}800$	(23)
$X^P_4 + d^-_{12} - d^+_{12} = 14{,}850$	(24)
$X^P_5 + d^-_{13} - d^+_{13} = 14{,}850$	(25)
$X^P_6 + d^-_{14} - d^+_{14} = 15{,}950$	(26)
$X^P_1 + X^R_2 + X^R_3 + X^R_4 + X^R_5 + X^R_6 - d^+_{15} = 2860$	(27)
$X^R_1 + X^R_2 + X^R_3 + X^R_4 + X^R_5 + X^R_6 - X^B_1 + d^-_{16} - d^+_{16} = 80$	(28)
$0.7X^a_{11} + 0.7X^a_{12} + 0.7X^a_{13} + 0.8X^a_{21} + 0.8X^a_{22} + 0.8X^a_{23} + 0.4X_{31} + 0.4X^a_{32} + 0.4X^a_{33} + 0.5X^a_{41} + 0.5X^a_{42} + 0.5X^a_{43} + d^-_{17} = 1380$	(29)
$X^a_{11} + X^a_{21} + X^a_{31} + X^a_{41} + d^-_{18} - d^+_{18} = 9000$	(30)
$X^a_{12} + X^a_{22} + X^a_{32} + X^a_{42} + d^-_{19} - d^+_{19} = 3500$	(31)
$X^a_{13} + X^a_{23} + X^a_{33} + X^a_{43} + d^-_{20} - d^+_{20} = 4000$	(32)
$X^a_{11} + X^a_{12} + X^a_{13} + X^a_{21} + X^a_{22} + X^a_{23} + X^a_{31} + X^a_{32} + X^a_{33} + X^a_{41} + X^a_{42} + X^a_{43} + d^-_{21} - d^+_{21} = 15{,}000$	(33)
$0.3X^a_{11} + 0.3X^a_{12} + 0.3X^a_{13} + 0.3X^a_{21} + 0.3X^a_{22} + 0.3X^a_{23} - 0.7X^a_{31} - 0.7X^a_{32} - 0.7X^a_{33} - 0.7X^a_{41} - 0.7X^a_{42} - 0.7X^a_{43} + d^-_{22} = 0$	(34)
$-0.3X^a_{11} - 0.3X^a_{12} - 0.3X^a_{13} - 0.3X^a_{21} - 0.3X^a_{22} - 0.3X^a_{23} + 0.7X^a_{31} + 0.7X^a_{32} + 0.7X^a_{33} + 0.7X^a_{41} + 0.7X^a_{42} + 0.7X^a_{43} - d^+_{23} = 0$	(35)
$-0.6X^a_{11} - 0.6X^a_{12} - 0.6X^a_{13} + 0.4X^a_{21} + 0.4X^a_{22} + 0.4X^a_{23} - 0.6X^a_{31} - 0.6X^a_{32} - 0.6X^a_{33} + 0.4X^a_{41} + 0.4X^a_{42} + 0.4X^a_{43} + d^-_{24} - d^+_{24} = 0$	(36)

Web Applications

Web-based DSS is important for strategic decision-making process. More effective DSS can be implemented by web-based model dealing with organizational view in decision-making processes. Recent DSS applications take advantage of the opportunities in web technologies, along with other internet technologies. With this perspective, web-based DSS can be one of the most promising options, increasing core business competition in the new health-care market environment. However, simply making an existing DSS accessible by using a web technology to hospital managers, patients or other stakeholders will often lead to unsatisfactory results and less competitiveness within the market. Developing the user interface, modeling, data mining for web-based DSS remains hard and major tasks. Thus, developing web-based DSS model should be considered system's flexibility for the future expansions. Figure 1 shows brief web-based DSS components along with their relationships.

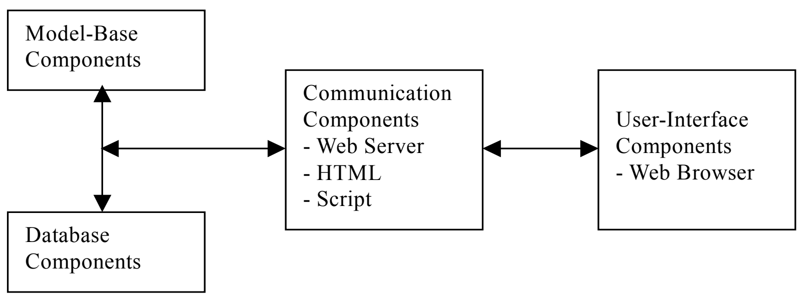

Figure 2. Web-Base Decision Support System Components

The hospital has launched its strategic DSS model with on-going base. The hospital top decision-makers have accepted the final results as valid and feasible outputs for implementing the DSS model in their web environment. The effects from this model outputs will be evaluated in the next two or three fiscal years, since any mistakes in medical and clinical management may result in serious damage for the patients and the hospital operations and performance. The future agenda will be arranged to compare with this proposed DSS model for hospital BPR planning. The BPR planning based on the model will provide the management with a significant insight to set an appropriate hospital resource planning and order communication system in their web environment, while meeting customer demand and enhancing competitive advantages. Thus, the hospital currently reviews all these planning strategies as the possible alternative operations.

CONCLUSION

In today's information technology age, rapid penetration of web technology into a business process enables more efficient and strategic management decisions. The health-care environment is not an exception to this trend. The growth of web technology can allow decision-makers to overcome many of the challenges confronting health-care systems. Health-care business environments are dramatically changing with multiple and complicated decision-making problems. The global health-care environment provides new business markets to management.

The DSS model for hospital business process planning is developed and analyzed to aid total resource planning. The health-care system in this study considers the proposed DSS model as the potential business strategies. Thus, this study provides both the satisfying solution and other important implications.

This study's contributions are as follows. This proposed DSS model enhances a practical way for planning the hospital business process planning considering tangible and intangible business aspects. Previous studies in DSS are limited to covering simultaneously comprehensive issues such as patient admission, hospital capacity, financing, manpower, and revenue. This study provides the management with insights improving overall performance through web-enabled hospital business process. This study utilizes an integrated multicriteria decision-making model that most previous studies in developing DSS models have not been explored in health-care area. The proposed results make better implication and more meaningful suggestions to the real decision-making settings.

The hospital decision-makers have accepted the final results as valid and feasible for implementing the hospital business process planning in real-situation. This proposed model's outputs will be evaluated during the next two or three fiscal years. In short, in situations where many complex e-business activities and conditions are involved, it can be much more practical to use the proposed DSS model to find a satisfying solution, especially when time and resources are limited.

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REFERENCES

Ackermann, F.L., R.M. Walls & M. Borman, (1999). Taking a strategic view of BPR to develop a multidisciplinary framework, *Journal of the Operational Research Society*, 50(3), 195-204.

Aldowaisan, T.A. & L.K. Gaafar, (1999). Business process reengineering: an approach for process mapping, *OMEGA*, 27(5), 515-524.

Collen, M.F., (1999). A vision of health care and information in 2008, *Journal of American Medical Information Association, 6*(1), 1-5.

Corlett, H., L. Maher & J. Sidman, (1998). Re-engineering day surgery, *Ambulatory Surgery*, 6(2), 85-88.

Courtney, J.F., (2001). Decision making and knowledge management in inquiring organizations: toward a new decision-making paradigm for DSS, *Decision Support Systems*, 31(1), 17-38.

Davenport, T.H. & J. Short, (1990). The new industrial engineering: information technology and business process redesign, *Sloan Management Review*, 31(4), 11-27.

De Veries, T. & R.E. Beekman, (1998). Applying simple dynamic modeling for decision support in planning regional health care, *European Journal of Operational Research*, 105(2), 277-284.

Forgionne, G.A. & R. Kohli, (1996). HMSS: a management support system for concurrent hospital decision making, *Decision Support Systems*, 16(3), 209-229.

Grimson, J., (2001). Delivering the electronic healthcare record for the 21st century, International *Journal of Medical Informatics*, 64(2-3), 111-127.

Gorry, G.A. & M.S. Morton, (1971). A framework for management information system, *Sloan Management Review*, 13(1), 50-70.

Ho, S.J., L. Chan & R.E. Kidwell, (1999). The implementation of business process reengineering in American and Canadian hospitals, *Health Care Management Review*, 24(2), 19-31.

Kettinger, W.J., J.T.C. Teng & S. Guha, (1997). Business process change: a study of methodologies, technologies and tools, *MIS Quarterly*, 21(1), 55-80.

Kohli, D., F. Piontek, T. Ellington, T. Vansdol, M. Shepard & G. Brazel, (2001). Managing customer relationships through E-business decision support applications: a case of hospital--physician collaboration, *Decision Support Systems*, 32(2), 171-187.

Kohn, D. (1994). The role of business process reengineering in health care, *Top Health Information Management*, 14(3), 1-6.

Kursters, R.J. & P.M.A. Groot, (1996). Modeling resource availability in general hospitals design and implementation of a decision support model, *European Journal of Operational Research*, 88(3), 428-445.

Lee, C.W. & N.K. Kwak, (1999). Information resource planning for a health-care system using an AHP-based goal programming method, *Journal of the Operational Research Society*, 50(12), 1191-1198.

Li, L.X., W.C. Benton & G.K. Leong, (20020. The impact of strategic operations management decisions on community hospital performance, *Journal of Operations Management*, 20(4), 389-408.

Mangiameli, P., D. West. & R. Rampal, (2004). Model selection for medical diagnosis decision support systems, *Decision support Systems*, 36(3), 247-259.

Miller, R.A., (1994). Medical diagnostic decision support systems--past, present, and future: a threaded bibliography and brief commentary, *Journal of the American Medical Informatics Association*, 1(1), 8-27.

Min, H., (19980. A personal-computer assisted decision support system for private versus common carrier selection, *Transportation Research Part E*, 34(3), 229-241.

Mosmans, A., J. Praet & C. Dumont, (20020. A decision support system for the budgeting of the Belgian health care system, *European Journal of Operational Research*, 139(2), 449-460.

Newman, K., (19970. Towards a new health care paradigm, patient-focused care: the case of Kingston Hospital Trust, *Journal of Management in Medicine*, 11(5-6), 357-371.

Pedersen, M.K. & M.H. Larsen, (2001). Distributed knowledge management based on product state models: the case of decision support in health care administration, *Decision Support Systems*, 31(1), 139-158.

Rao, G.R. & M. Turoff, A hypermedia-based group decision support system to support collaborative medical decision-making, *Decision Support Systems*, 30(2), 187-216.

Saaty, T.L., (1980). *The Analytic Hierarchy Process*, New York: McGraw-Hill.

Sarker, S. & A.S. Lee, (1999). IT-enabled organizational transformation: a case study of BPR failure at TELECO, *The Journal of Strategic Management Information System*, 8(1), 83-103.

Seymour, D.W. & W.V. Guillett, (1997). Connecting the dots: grounding quality improvement and cost cutting initiatives in strategic planning, *Journal of Healthcare Resource Management*, 15(7), 14-19.

Sheng, O.R.L., (20020. Decision support for health care in a new information age, *Decision Support Systems*, 30(2), 101-103.

Shim, J.P. , M. Warkntin, J.F. Courtney, D.J. Power, R. Sharda & C. Carlsson, (2002). Past, present, and future of decision support technology, *Decision Support Systems*, 33(2), 111-126.

Short, J. & N. Venkatraman, (1992). Beyond business process redesign: redefining Baxter's business network, *Sloan Management Review*, Fall, 7-21.

Stoddard, D.B. & S.L. Jarvenpaa, (1995). Business process redesign: tactics for managing radical change, *Journal of Management Information Systems*, 12(1), 81-107.

Teng, J.T.C., V. Grover & K.D. Fiedler, (1996). Business process reengineering: charting a strategic path for the information age, *California Management Review*, 36(3), 9-31.

Vissers, J.M.H. (1998). Patient flow-based allocation of inpatient resources: a case study, *European Journal of Operational Research*, 105(2), 356-370.

ETHICS OF COMPUTER USE: A SURVEY OF STUDENT ATTITUDES

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ABSTRACT

The potential for misuse of computer systems and resources has been an important issue for many years. The rapid growth in use of remote access systems, the use of the internet and distributed systems for financial and other sensitive transactions, and the expansion in the availability of products in digital form is causing ethical issues surrounding misuse of computer resources to become an increasingly serious problem.

This paper surveys ethical attitudes of a set of undergraduate business majors. The survey presents sets of scenarios in which students are asked to indicate whether a particular action is ethical or unethical using a 7 level Likert scale. Alternative base scenarios have been designed to present ethical issues relating to various types of unauthorized access to computer resources. Other sets of base scenarios focus on the use of computers to illegally copy products (software and music recordings). In addition, for each base scenario, alternative sub-scenarios are presented in which the motives of the individual vary between intellectual curiosity, securing resources for personal use, profit, and malice toward the affected entity. The scenarios are designed to provide an evaluation of how the level of malicious intent in the action affects the students' perception of the degree to which the action represents a breach of ethics.

Results of this survey suggest that the intent of the individual engaging in unauthorized access or illegal copying does substantially affect student perceptions of the degree to which the behavior is a violation of ethics. In general, actions undertaken for profit or malicious intent are judged to be less ethical than the same actions undertaken for intellectual curiosity or to secure resources for personal use. In addition, a very strong majority of the students surveyed believe that any active participation in downloading is unethical.

INTRODUCTION

As the amount of corporate and personal information continues to grow and the access to that information by IT personnel increases, ethics and value judgments by IT professionals becomes more important. Research in information systems security and control, has reported large losses attributable to unethical activities (Straub, 1986). Pearson et al. define three factors which require further study of ethical behavior of IS professionals. These include a greater reliance on IT systems across the business enterprise, increasing use of system generated information for decision making, and the lack of single unified code of ethics for all IT personnel (Pearson, et. al., 1996).

Professional organizations like ACM and DPMA have implemented an ethical code of conduct. In addition, organizations are increasingly establishing codes of ethics for internal use with about 93% of U.S. firms having such codes in place in 1992 (Berenbeim, 1992). Unfortunately, many of these codes are either very general statements which are difficult for workers to translate into individual situations or, in some cases the ethical statements are viewed by workers with a certain denial of responsibility (Harrington, 1996). As a result, gaining understanding of ethical issues is best accomplished through the use of scenarios. These scenarios must be specific and engage the participant. Integration of ethics topics has been recommended for the computer science curriculum (Miller, 1992) and specific approaches for delivery of this content, through scenarios, have been explored within an Information Systems curriculum (Couger, 1989). Both the ACM and DPMA have included ethical issues as a part of their recommended standard curriculum for schools. Students studying under general business or Information Systems Curriculum should be given knowledge about ethics issues.

Computer Science and Information System students will compose our future IT workforce. A survey of ethical attitudes of these students can be used as a proxy for ethical attitudes of entry level IT workers. Previous surveys of business students Slater, 1991) have shown that more than one-half of respondents claimed they had engaged in unethical computer activity, including hacking or illegal copying of software. This corresponds with surveys of industry abuse regarding the ownership of intellectual property. Losses for software developers attributable to piracy in 1996 were estimated to be 11.2 billion (SPA/BSA, 1997). This emphasizes the need for continued study of the ethical beliefs and value judgments made by students.

STUDENT PERCEPTIONS

Paradice first evaluated student perceptions based on 12 scenarios (Paradice, 1990). Although the study lacked rigorous statistic analysis, three motives for ethical behavior were defined. Motives were defined for obligation, opportunities, and intent. Each scenario presented an ethical situation to which MIS and non-MIS students responded. He concluded that MIS students had stronger notions of professional responsibility, and that non-MIS students were more tolerant of software piracy. However, a study by Im and Hartman (1990) was not able to confirm divergent ethic perceptions between MIS and non-MIS students.

Generally students rated situations concerning opportunity and intent as unethical. However, results were mixed for obligations to clients and companies (Paradice, 1990). This behavior of opportunity and intent was confirmed by Whitman, et. al. with greater statistical rigor. In addition, through a rigorous application of multivariate factor analysis revealed that ethical motives (factors) could be more correctly represented by misuse of corporate resources, illicit use of software or software license infringement (Whitman, et. al., 1999).

The mixed results experienced by Paradice were confirmed by Calluzzo and Cante in a survey of graduate and undergraduate students. Students often represented misconceptions about ethical and non-ethical behavior in response to questions. Students agreed that behavior was unethical if it was a matter of personal privacy or theft of software. However when the questions concerned property or privacy violations for the enterprise or business, many student responses were neutral when a clear ethical violation occurred (Calluzzo and Cante, 2004). Couger's earlier study (Couger, 1989) had also found that students were indifferent about enterprise piracy.

Ethical perceptions have been found to differ between industry professionals and students. Generally, greater IS experience produced stricter ethical interpretations. Older IS professionals rated situations as unethical where students or younger professionals allowed a more liberal interpretation (Prior, et. al. 2002). Behavior, including the production of software with bugs, or reducing testing efforts to bring a project within time and budget, was considered acceptable and not viewed as unethical by students. This result was confirmed when student responses were compared to those of industry experts (Athey, 1993). Justification for the differential was attributed to lack of experience, student income level, or just that students see this behavior everyday in the business world, and so perceive it as acceptable behavior.

In explaining the student ethical evaluations, studies have used a variety of demographic factors like age, gender, computer experience, academic major or knowledge of programming languages (Whitman, et. al., 1999), income level (Athey, 1993) or just gender (Leventhal, et. al., 1992) Some evidence supports that male and female responses will differ (Leventhal, et. al., 1992). However, the results vary depending on the type of question.

APPROACH

This study examines differences in perceived motivation or intent of an action and how these differences in intent affect student ethical evaluations. Student perceptions of how seriously ethical behavior is breached in a number of scenarios describing unauthorized access to computer systems, or use of computers in the illegal copying/distribution of copyrighted materials are examined. While a number of studies have looked at similar issues, few have rigorously examined how the motivation for the unauthorized access or illegal copying affects our ethical assessment of this behavior.

The focus on intent is created by presenting alternative scenarios in which the type of access or copying is identical, but where the motivation of the individual involved and the use made of the unauthorized access or illegal copies is varied. Scenarios are presented in which the incident of misuse, unauthorized access, or illegal copying is motivated by a variety of factors including – intellectual curiosity, malicious use of resources, obtaining resources for personal use or to support non-profit motivated activities, or obtaining resources for profit. We hypothesize that acts motivated by profit or malice will be viewed as more severe breaches of ethics than the same acts performed to satisfy intellectual curiosity or to obtain resources not used for profit.

THE SURVEY INSTRUMENT

The question set used is adapted from one developed by Paradice (1990). Paradice defined three motivations for his question set, consisting of obligation, opportunity, and intent. Since the purpose of the study was to identify levels of perceived intent, where intent was judged based on the level of malice, Paradice's questions on the motivation of obligation were deleted. Questions from the opportunity motivation were used essentially unchanged and questions from the intent motivation were both extended to provide better clarification of actor intent and supplemented with additional questions relating to software piracy.

A follow-on study applying a rigorous factor analysis to Paradice's question set isolated three specific factors (Whitman, et. al., 1999). These ethical factors were defined as software license infringement, illicit use (writing and disseminating viruses or causing a system crash), and misuse of corporate resources. To ensure comprehensive coverage of these factors affecting ethical decision making, this question set was mapped to these factors replacing the original motivations defined by Paradice. Questions 1 and 2 map to misuse of corporate resources, 3 and 4 map to illicit use, and 5, 6 and 7 map to license infringement.

The nature of the software referred to in each question (Word processing vs. Web Bots) was also changed to reflect the timeframe of this study, since the original work was created nearly 15 years ago. In addition, we have systematically increased the number of alternative scenarios in which the type of unauthorized access or license infringement was the same but the motive and type of use differed.

This survey was administered to students in a junior level management information systems (MIS) course at an AACSB accredited school of business which includes an outside ethics course in addition to ethics content included throughout the business core courses. The survey was administered across multiple sections serving different populations. One section, with 30 respondents, was an on-line section whose students were predominantly participants in a web-based undergraduate degree program for students with community college degrees relating to information technology. The remaining sections, with 37 respondents, were open to all business majors and were taught in face-to-face mode with supplemental materials, including the survey, provided on-line.

It seems reasonable to assume that the students in the on-line section were, in general, more sophisticated in their knowledge and experience with the use of computer systems, but would this affect their ethical perspectives. Greater knowledge of potential abuses in computer systems might make students more sensitive to the dangers of abusing computer privileges, and the fact that many of the students in the online course were headed for IT related careers might make them more sensitive to the codes of ethics and professional obligations relating to computer use. For these reasons we hypothesize that the students in the on-line section for students pursuing IT related careers will tend to view the ethical breaches in each of the scenarios as more severe than the general business students in the face-to-face sections. Comparisons between the two types of students are presented in the last empirical results sub-section below.

Survey Questions asked respondents to rate the behavior described in each scenario on a 7 point, centered, Likert scale. The response choices presented were 1) very ethical, 2) ethical, 3) somewhat ethical, 4) questionable, 5) somewhat unethical, 6) unethical, and 7) very unethical. Seven fundamental ethical scenarios were presented. However, variations with modification in the motivation for the action described were presented for most of the scenarios leading to a total of 19 questions. Two of the base scenarios and 4 total questions dealt with instances of misuse of corporate computer resources, Two base scenarios and 5 questions dealt with instances of illicit use of (unauthorized access to) computer resources. Finally, three base scenarios and 10 questions dealt with aspects of illegal copying and/or distribution of copyrighted software or digitized music. The questions used are listed in the heading area of each table of survey results presented below. In describing these empirical results, we will cover the scenarios, by category, in the order described above.

SURVEY RESULTS

In the tables of results presented below, the distribution of responses across the whole survey group (67 observations) is presented along with an indication of the percentage of respondents selecting each response. The median response is also indicated by that response being shown in bold faced type.

Likert scales provide data that are ordinal in nature. Although Likert scale data has often been analyzed using statistics designed for cardinal data, it is more appropriate to use nonparametric statistical tests that are valid for ordinal data (Classon and Dormody, 1994).

In the results presented below, the single sample Wilcoxin signed-ranks test for differences in paired responses is used to assess differences in response across scenarios posing the same action but with variations in the motivation for the action. Given that the data were coded so that a 1 means very ethical and a 7 means very unethical, a positive value for the signed rank statistic S means that respondents believed the first item in the pair to be less ethical than the second. Thus, for instance, the substantial negative value for the S statistic in the comparison of Question 1A with Question 1B in Table 1 indicates that respondents believe that the student's actions in finding the security loophole represented less of an ethical breach than the student's actions in using the loophole to access other students' records. The probability that the observed S value could have occurred when there is no difference in the population's rankings of the two items is shown in parentheses below each S value and results that are significant at the .05 level are indicated by an asterisk in the table results presented here.

Misuse of Corporate Resources

The first scenario of misuse of corporate resources presented is the one summarized in Table 1. A student finds a loophole in the security of a university computer system**.** The alternative scenarios assess the ethics of the student in finding the loophole, and in using it to access private information of other students. On average, respondents found the student's action in finding the loophole somewhat unethical, but found his or her action in exploiting the loophole, scenario B, significantly more unethical. Scenario C under this question deals with the actions of the administrator of the system that was breached, and the obligation to protect users for breaches of privacy. Respondents on average felt that the response of the system administrator was of questionable ethics, but felt that it was significantly less unethical than the actions of the student in accessing other students' records.

Table 1

A student suspected and found a loophole in the university computer's security system that allowed him to access other students' records. He told the system administrator about the loophole, but continued to access others' records until the problem was corrected 2 weeks later.

A. The student's action in searching for the loophole was
B. The student's action in continuing to access others' records for 2 weeks was
C. The system administrator's failure to correct the problem sooner was

	A		B		C	
	Count	Pct.	Count	Pct.	Count	Pct.
Very Ethical	2	2.99	0	0.00	0	0.00
Ethical	10	14.93	0	0.00	2	2.99
Somewhat Ethical	5	7.46	2	2.99	1	1.49
Questionable	12	17.91	0	0.00	29	43.28
Somewhat Unethical	**5**	7.46	2	2.99	**12**	17.91
Unethical	14	20.90	16	23.88	10	14.93
Very Unethical	19	28.36	**47**	70.15	13	19.40
			B		C	
Paired Signed Ranks Test for			S- Stat.	p - H0	S- Stat.	p - H0
Scenario A vs. ___			-351.50	(<.001), 0	-16	-0.87
Scenario B vs. ___					571.5	(<.001), 0

Table 2 presents a single scenario of a programmer at a bank modifying an accounting information system to avoid a service charge on his personal account. Respondents on average found this behavior unethical with a near majority finding it very unethical.

Table 2

A programmer at a bank realized that he had accidentally overdrawn his checking account. He made a small adjustment in the bank's accounting system so that his account would not have an additional service charge assigned. As soon as he made a deposit that made his balance positive again, he corrected the bank's accounting system.

	Count	Pct.
Very Ethical	1	1.49
Ethical	2	2.99
Somewhat Ethical	4	5.97
Questionable	2	2.99
Somewhat Unethical	5	7.46
Unethical	**26**	38.81
Very Unethical	27	40.30

Table 3

A manager of a company that sells computer processing services bought similar services from a competitor. She used the service for over a year and always paid her bills promptly.

A. She used her access to the competitor's computer to try to break the security system and cause the system to "crash."

B. She used her access to the competitor's computer to identify other customers, and used this information to identify sales prospects.

	A		B	
	Count	Pct.	Count	Pct.
Very Ethical	0	0.00	1	1.49
Ethical	1	1.49	2	2.99
Somewhat Ethical	1	1.49	5	7.46
Questionable	2	2.99	10	14.93
Somewhat Unethical	5	7.46	13	19.40
Unethical	14	20.90	**19**	28.36
Very Unethical	**44**	65.67	17	25.37
Paired Signed Ranks Test for			S- Stat.	p - H0
Scenario A vs. Scenario B			428.00	(<.001), 0

Illicit Use of Computer Resources

Table 3 presents results for a scenario in which a manager of a company subscribes to online services provided by a competing company. Two alternatives of this scenario have the manager using information she obtained to identify sales prospects in one case and to attempt to crash the competitors on-line system in the alternative scenario. On average respondents felt that using the competitor's own system to identify prospects was unethical while using it to crash the competitor's system was overwhelmingly viewed as very unethical.

Table 4

Dilbert develops a set of programs that allow him to find vulnerable computers on the internet and install "bots" on them. These bots can be controlled by Dilbert to initiate e-mail from each computer infected with a "bot."

A. Dilbert uses these bots to flood the site of a corporation that is widely believed to have exploitive labor and environmental practices, causing the businesses web site to be unavailable for several hours. The bots cause no other damage to the affected systems and are not used for any other purposes. Dilbert's behavior is

B. Dilbert uses these bots to take over the infected PCs when they are not in use and use these computing resources to help him calculate the value of PI 8 billion decimal places. His bots cause no damage to the infected systems and never operate when there are not idle resources. Dilbert's behavior is

C. Dilbert uses these bots to flood the site of an online business for several hours. He then demands that this business pay $50,000 to an "offshore" untraceable account and threatens to repeat the attack until the business makes this payment. Dilbert's behavior is

	A		B		C	
	Count	Pct.	Count	Pct.	Count	Pct.
Very Ethical	1	1.49	0	0.00	1	1.49
Ethical	1	1.49	1	1.49	1	1.49
Somewhat Ethical	2	2.99	3	4.48	3	4.48
Questionable	10	14.93	8	11.94	2	2.99
Somewhat Unethical	7	10.45	6	8.96	1	1.49
Unethical	**22**	32.84	**28**	41.79	8	11.94
Very Unethical	24	35.82	21	31.34	**51**	76.12
			B		C	
Paired Signed Ranks Test for		S- Stat.	p - H0		S- Stat.	p - H0
Scenario A vs. ___			-24.5	-0.56	-214.5	(<.001), 0
Scenario B vs. ___					-247	(<.001), 0

Table 4 presents a set of scenarios about a programmer installing "bots" on vulnerable computers on the internet and using them in a variety of ways. In the first alternative he uses the bots to launch a denial of service attack against the web site of a company that he believes engages in exploitive behavior. In the second scenario, he simply uses the bots for his own amusement to calculate the value of Pi. Finally in the third scenario he ultimately uses the bots to extort money for personal gain.

Not surprisingly, respondents overwhelming found the use of the bots for personal gain to be very unethical and found this behavior more unethical than the other 2 scenarios. Perhaps more surprising is the fact that, when the target of a denial of service attack was a company thought to engage in exploitive practices, respondents did not feel that use of the bots in a denial of service attack was less ethical than just using them for personal amusement.

Illegal Copying and Distribution

Three base scenarios of illegal copying and or distribution of copyrighted materials are presented here with variations involving differences in how widely the materials are distributed and whether profit is involved. The first scenario involves improper copying and use of computer software, while the remaining scenarios deal with downloading or copying copyrighted music.

Table 5

A student legally obtained a copy of a popular word processing software package. The software license agreement allowed use "for educational purposes only" and required the student to remove the software from her computer once she was no longer a student. She kept the word processing software on her computer after graduation and used it

A. to support her volunteer work for a charitable organization. Her Behavior was
B. for personal correspondence and job search activities. Her Behavior was
C. in support of a for-profit business services company that she developed. Her behavior was

	A		B		C	
	Count	Pct.	Count	Pct.	Count	Pct.
Very Ethical	4	5.97	5	7.46	`2	2.99
Ethical	3	4.48	2	2.99	1	1.49
Somewhat Ethical	4	5.97	6	8.96	3	4.48
Questionable	21	31.34	19	28.36	10	14.93
Somewhat Unethical	**16**	23.88	**18**	26.87	15	22.39
Unethical	14	20.90	14	20.90	**20**	29.85
Very Unethical	5	7.46	3	4.48	16	23.88
			B		C	
Paired Signed Ranks Test for			S- Stat.	p - H_0	S- Stat.	p - H_0
Scenario A vs. ___			-2.00	-0.97	-290	(<.001), 0
Scenario B vs. ___					-305.5	(<.001), 0

Table 5 presents 3 variations of a scenario in which a student with a legal license to use a software package for educational purposes retained that software in violation of the license agreement after graduation. In one alternative she used the software to support work for a charitable organization, in another she used it for personal and job search activities, and in the third she used it in a for-profit company. The median response to the charitable and personal uses was that these uses were somewhat unethical. However, respondents felt that use of the software in a for-profit venture was more unethical than the other uses. The median response indicated this behavior was believed to be unethical and about a quarter of the respondents felt it to be highly unethical.

Table 6

Andy downloads a copy of a CD by a famous artist recorded on a major record label from an illegal site.

A. He keeps this music on his own PC and MP3 player. Andy's behavior is
B. He sends copies of this music to 3 of his friends. Andy's behavior is
C. He makes copies of this music available (for free) to anyone requesting them on the web. Andy's behavior is
D. He makes copies of this music on a CD and sells them. Andy's behavior is

	A		B		C		D	
	Count	Pct.	Count	Pct.	Count	Pct.	Count	Pct.
Very Ethical	4	5.97	3	4.48	3	4.48	1	1.49
Ethical	2	2.99	1	1.49	2	2.99	0	0.00
Somewhat Ethical	4	5.97	1	1.49	2	2.99	1	1.49
Questionable	14	20.90	8	11.94	4	5.97	1	1.49
Somewhat Unethical	**12**	17.91	11	16.42	7	10.45	2	2.99
Unethical	16	23.88	**17**	25.37	**21**	31.34	8	11.94
Very Unethical	15	22.39	26	38.81	30	44.78	**54**	80.60
			B		C		D	
Paired Signed Ranks Test for			S- Stat.	p - H0	S- Stat.	p - H0	S- Stat.	p - H0
Scenario A vs.			-300.00	(<.001), 0	-367	(<.001), 0	-580	(<.001), 0
Scenario B vs.					-85.5	0.00, 0	-315	(<.001), 0
Scenario C vs.							-253	(<.001), 0

Table 6 presents a set of scenarios relating to use and distribution of software illegally copied from a web site. Alternatives involving keeping the music for personal use, providing copies to friends, providing copies for no gain on the web, and selling copies of the downloaded music for personal gain were evaluated by respondents. Evaluation of the median responses and results of the signed-rank test indicate that our survey respondents felt that each of these activities involved progressively greater violations of ethics. Respondents overwhelmingly found the sale of such downloaded music for profit to be very unethical. In fact the proportion of respondents finding this behavior very unethical was the highest of that for any of the scenarios and alternatives presented in this study.

Table 7

At a concert, Mandy buys a copy of a CD self produced by a local band.

A. She makes electronic copies of this music and sends them to 3 of her friends. Mandy's behavior is
B. She makes copies of this music available (for free) to anyone requesting them on the web. Mandy's behavior is
C. She makes copies of this music on a CD and sells them. Mandy's behavior is

	A		B		C	
	Count	Pct.	Count	Pct.	Count	Pct.
Very Ethical	2	2.99	2	2.99	1	1.49
Ethical	5	7.46	3	4.48	0	0.00
Somewhat Ethical	3	4.48	5	7.46	0	0.00
Questionable	22	32.84	16	23.88	3	4.48
Somewhat Unethical	**11**	16.42	**8**	11.94	4	5.97
Unethical	18	26.87	18	26.87	18	26.87
Very Unethical	6	8.96	15	22.39	**41**	61.19
			B		C	
Paired Signed Ranks Test for			S- Stat.	p - H0	S- Stat.	p - H0
Scenario A vs. ___			-180.00	0.00, 0	-733	(<.001), 0
Scenario B vs. ___					-564	(<.001), 0

Table 7 presents scenarios similar to those of Table 6, except that here the music was originally purchased legally and was performed by a local band. Alternatives involving distribution to a few friends, making the music available to any one on the internet with no personal gain, and copying and selling the CD for personal gain were evaluated by respondents. Once again our respondents found each of these scenarios to represent successively greater breaches of ethics. While the majority of respondents found sale of the copied CDs to be very unethical, it is interesting that respondent tended to view each of the alternatives in Table 7 as slight less severe violations of ethics than the corresponding alternatives presented in Table 6. Evidently, the fact that the copy was initially obtained by illegal means made respondents more critical of further uses of the music.

Comparisons Among Groups

As noted above the survey was completed both by a set of general business majors and by a separable set of students who were predominantly IS related majors in an on-line class. To see if these groups differed, we tested for differences in response between the predominantly IS student on-line section and the face-to-face sections consisting of general business majors. In this assessment, we treated the two types of sections as independent samples and performed a Chi-Square test for differences between the two samples. Results of the Chi-Square test are recorded as a Z-statistic where, for the given sample size, values greater than two generally indicate that the mean responses of the two groups are different using the standard .05 probability level for rejecting the null hypothesis of equality. The samples were ordered in a manner that causes the Z-statistic to be negative when the students in the on-line, IS oriented program rated the behavior in a scenario as less ethical than the class of general business majors. Chi-Square test results that are significant at the .05 level are also indicated by an asterisk.

Table 8: **Chi-Square Tests for Differences in Ethical Valuations Between IS Students and General Business Majors**

	Sub-Scenario			
	A	B	C	D
	Z-Value	Z-Value	Z-Value	Z-Value
Scenario 1	-2.00*	-1.01	-1.43	
Scenario 2	0.49			
Scenario 3	0.16	-2.46*		
Scenario 4	-0.49	-0.42	-1.17	
Scenario 5	-1.47	-0.99	-1.08	
Scenario 6	-1.50	-1.41	-1.47	-0.91
Scenario 7	-2.54*	-1.54	-0.39	

The results shown in table 8 suggest that the differences between the two groups are of only modest magnitude. While the sign of the Z-statistic indicates that the online, IS oriented, students were usually more negative in their ratings of behavior in nearly every scenario, the differences were only statistically significant in 3 of 20 cases. It is interesting that the statistically significant values all came in the variant of a given scenario that was viewed as least unethical. It appears that perhaps IS oriented students are less tolerant of modest breaches of ethics, while both groups find more serious breaches equally egregious.

CONCLUSIONS

This paper presents the results of a survey of ethical attitudes among undergraduate business majors and IS majors. Students evaluated various scenarios related to the use of computer systems by individuals. These scenarios presented the student with a number of varying degrees of activity that could be judged in terms of their level of ethical or unethical activity. The judgment made by the student was on a scale of Very Ethical to Very Unethical with five levels in between. Sixty seven students participated in the survey.

Table 9: Summary Results

Scenario	M	B	C	D
1. Loophole in Computer System				
A. Student searches for loophole	su	*-351*	-16	
B. Student accesses other student's records	vu		*571*	
C. System Administrator fails to correct problem on a timely basis	su			
2. Company manager using a competitors similar services				
A. Tries to break security system to cause competitors system to crash	vu	*428*		
B. Used access to identify customers for sales prospect	u			
3. Programmer at bank makes change in code to eliminate a fee				
Code is changed back to original as soon as the balance is updated	u			
4. Population of "bots" on computers using the Internet				
A. Causes a website of a company with questionable labor and environmental practices to be unavailable for a few hours.	u	-24	*-214*	
B. Causes infected PCs in companies to calculate Pi to 8 billion decimals when those PCs have idle resources	u		*-247*	
C. Causes degraded service of an online site for hours and demands a ransom to remove the "bots"	vu			
5. Student's use of software for educational use only				
A. Uses the software as a volunteer for charitable organizations	su	-2	*-290*	
B. Uses the software for correspondence and job search activities	su		*-305*	
C. Uses the software for a for-profit business services company she started	u			

Table 9: Summary Results				
Scenario	M	B	C	D
6. Download of a music CD by a famous artist on a major record label				
A. Uses the music on personal PC and MP3 player	su	*-300*	*-367*	*-580*
B. Sends copies of music to 3 friends	u		*-85*	*-315*
C. Makes copies of music available to anyone accessing his website	u			*-253*
D. Makes copies on CDs and sells them	vu			
7. Purchase of CD sold by a local band				
A. Makes copies on CD to give to friends	u	*-180*	*-733*	
B. Sends copies on CD to anyone requesting the CD on her website	u		*-564*	
C. Makes copies on CD and sells them	vu			
Column M - Median response (Very Ethical, Ethical, Somewhat Ethical, Questionable, Somewhat Unethical, Unethical, Very Unethical				
Columns B, C, D – Wilcoxin signed-rank value for differences in paired responses. Example: 1A (minus value) is much less of an ethical breach compared to 1B. 1A and 1C are about the same. 1B (plus value) is much more of an ethical breach as compared to 1C.				

The results of the survey are summarized in Table 9. The table shows the median ranking for each activity and also the score for the test for differences between the different activities for each scenario - statistically significant values are italicized. The median rank for all activities is in the range of somewhat unethical to very unethical. The results show that the **intent** of an individual engaging in the activity does alter the students' perception of the level of ethical behavior. Personal use of software, or downloads was judged more as being just somewhat unethical as was hacking into a computer system for reasons of intellectual curiosity. Malicious activity (scenarios 1, 2, 3 and 4) however, was judged primarily in the unethical to very unethical range. Accessing other peoples records, changing code for personal gain, and causing reduced response time on company PCs was judged to be in the unethical to very unethical range. However, causing reduced response time for a company that was believed to exploit its workers and was unfriendly to the environment was viewed no more negatively than the same activity performed without malicious intent. Sharing illegal copies with others was seen as less ethical than just personal use of such copies, and profiting from the illegal reproduction of music CD was overwhelmingly judged to be highly unethical. Very little difference was observed between the IS and general business groups of students. It appeared the IS students were a little less tolerant of modest breaches of ethics.

Further research should be done using other populations of students, industry users, and non industry home users to see if there are differences in attitudes among different types of users. Also, future research should examine the effects of ethics curriculum and the use of codes of ethics by conductive comparative studies of students before and after exposure to ethics instruction.

ENDNOTES

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REFERENCES

Athey, Susan (1993). A Comparison of Experts' and High Tech Students' Ethical Beliefs in Computer-related Situations, *Journal of Business Ethics* (12), 359-370.

Berenbeim, R.E. (1992).Corporate Ethics Practices, The Conference Board, New York, 7-10.

Calluzzo, V. and C. J. Cante (2004). Ethics in Information Technology and Software Use, *Journal of Busines Ethics* (51), 301-312.

Classon, D. L. and T. J. Dormody (1994). Analyzing data Measured by Individual Likert-Type Items, *Journal of Agricultural Education*, 35(4), 31-35.

Couger, J. Daniel (1989).Preparing IS Students to Deal with Ethical Issues, *MIS Quarterly,* June, . 210-218.

Harrington, Susan (1996). Effect of Codes of Ethics and Personal Denial of Responsibility on Computer Abuse Judgments and Intentions, *MIS Quarerly*, September, 257-278.

Hilton, Thomas (2000). Information Systems Ethics: A Practitioner Survey, *Journal of Business Ethics* (28), 279-284.

Im, J. and S. Hartman (1990) Rethinking the Issue of Whether IS People Are Different From Non-IS People, *MIS Quarterly* March, 1-2.

Johnson, D.G. and J. Snapper (1984). *Ethical Issues in the Use of Computers*, Wadsworth, Belmont, CA..

Jones, T.M. (1991). Ethical Decision making by Individuals in Organizations: An Issue-Contingent Model, *Academy of Management Review* 16(2), 366-395.

Leventhal, L.M., K. E. Instone, and D. W. Chilson (1992). Another View of Computer Science Ethics: Patterns of Responses Among Computer Scientists, *Journal Systems Software* 17(1), 49-60.

Miller, K. (1989) Integrating Computer Ethics into the Computer Science Curriculum, *Computer Science Education* (1), 37-52.

Paradice, D.B. (1990) Ethical Attitudes of Entry-Level MIS Personal, *Information and Management* (18), 143-151.

Parker, D.B. (1979). *Ethical Conflicts in Computer Science and Technology*. Menlo Park, California, USA: AFIPS Press.

Pearson, J.M., L. Crosby, and J. P. Shim (1996). Modeling the Relative Importance of Ethical Behavior Criteria: A Simulation of Information Systems Professionals' Ethical Decisions, *Journal strategic Information Systems* 5(4), 275-291.

Prior, M., S. Rogerson, and B. Fairweather (2002). The Ethical Attitudes of Information systems Professional: Outcomes of an Initial Survey*, Telematics and Informatics* (19), 21-36.

Slater, D. (1991) New Crop of IS Pros on Shaky Ground, *Computerworld,* 90.

SPA/BSA (1997). Software Publishers Association/Business Software Alliance joint commissioned study: *1996 Global Piracy Report*, International Planning and Research, 1997.

Straub, D.W. (1986) *Controlling Computer Abuse: An Empirical Study of Effective Security Countermeasures*. University of Minnesota, Institute for Research on Management Information Systems, Minneapolis, MN.

Whitman, M.E., A. M. Townsend, and A. R. Hendrickson (1999).Cross-national Differences in Computer-use Ethics: A Nine-country Study, *Journal of International Business Studies* 30(4), 673.

THE PROBABILITY OF WINNING AND THE EFFECT OF HOME-FIELD ADVANTAGE: THE CASE OF MAJOR LEAGUE BASEBALL

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ABSTRACT

This paper examines the factors that affect the probability of a major league baseball team winning a game. The basic hypotheses of the study are that home teams are more likely to win a game than visiting teams, that teams that travel to arrive at a game are less likely to win the game than teams that don't, and that teams having a strong batting performance are more likely to win a game than teams having a weak batting performance. To examine these issues, we estimate five logit regressions from data for all 2,428 regular season games played during the 2004 season. We find that while the strength of a team's batting performance does affect its probability of winning, travel does not affect the likelihood of either the home team or visiting team winning a game. The major finding of the paper, however, is that contrary to the commonly held belief that a home-field advantage exists in major league baseball games, home teams only have an advantage over visiting teams in very close games. In games that are won by more than one run, the likelihood of winning is roughly equal for home teams and visiting teams.

INTRODUCTION

In major league baseball, like most other professional sports, the conventional wisdom is that a home-field advantage exists. Birnbaum (2004, p. 972) reports that home teams have historically won about 54 percent of their games. The difference between a 54 percent winning percentage and a 46 percent winning percentage is substantial since, during a standard 162-game season, a team that wins 54 percent of its games will accumulate 12 more victories than a team that wins 46 percent of its games. Twelve additional wins during the course of a season often makes the difference between a team going to the post-season playoffs and not going to the playoffs. In the two most recent seasons, 2003 and 2004, the first place team won fewer than twelve more games than the second place team in five of the six Major League Baseball divisions.[1]

One reason the home team has the advantage in baseball is the fact that they bat last, which becomes a factor in one-run victories. If a game enters the top of the last inning with the score tied, for example, the manager of the visiting team doesn't know whether his strategy should involve trying to score a single run, since he doesn't know whether or not one run will ultimately be enough to win the game. If the score is tied entering the bottom of the last inning, however, the manager of the home team knows that a single run will be enough to win the game, and he can therefore employ a strategy designed to score just one run. Another possible reason that a home team has an advantage is that the visiting team experiences travel-induced stress and fatigue. Since the visiting team must travel to arrive at a game, it incurs the inconveniences associated with travel, in terms of both the physical act of traveling and the act of staying in an unfamiliar city. In some cases the home team also incurs the inconvenience of travel.[2] If the home team does travel, they would be subjected to the same travel-induced fatigue as the visiting team, but they would not experience the discomfort of being away from the familiar surroundings of home. As such, when both teams travel to a game the visiting team is more likely than the home team to be adversely affected by the travel.

The primary purpose of this paper is to determine the effect that home-field advantage has on the probability of a team winning a major league baseball game played during the 2004 season. We also determine the effect that team batting performance and travel have on the probability of a team winning a game. Specifically, we will determine whether a home-field advantage exists and, if so, whether it exists generally or only in limited situations. To examine these issues we develop and estimate a series of binary logit regressions where the outcome of the game (i.e., win or lose) is the dependent variable.

In the next section we review the literature pertaining to the home-field advantage in major league baseball and to the analysis of factors affecting the run production of baseball teams. In the third section we discuss the data and descriptive statistics and report the probability of victory in various situations. In the fourth section we describe the logit regressions. In the fifth section we report and discuss the regression results. Finally, in the last section we present a summary of our major findings and offer some concluding remarks, including a suggestion for potential directions that future research on the subject of the home-field advantage might take.

REVIEW OF THE LITERATURE

A relatively new and popular field that applies statistical models and methodologies to baseball data is sabermetrics, which derives its name from the Society for American Baseball Research (SABR), an organization devoted to furthering the study of baseball. Birnbaum (2004, p. 963) defines sabermetrics as "the science of answering questions about baseball through the analysis of the statistical evidence." It has also been defined by Bill James, the man who popularized sabermetrics in the early 1980s in the initial versions of the annual *The Bill James Baseball Abstract*, as "the search for objective knowledge about baseball" (Grabiner).

The scholarly literature has examined several baseball related issues. Lindsey (1963), in one of the earliest academic studies pertaining to baseball performance, derives a formula that explains the number of runs a team scores based on the various components of its hitting production. Albert (1994) employs a Bayesian hierarchical model to determine which game-situations affect players' batting average and determines that several situations affect batting average: the pitch count faced by the batter, facing a pitcher of the opposite arm, facing a groundball pitcher, and playing in a home game. Albright (1993) conducts a statistical analysis of hitting streaks among major league batters during the 1987-1990 seasons and concludes that hitting streaks happen at about the same rate as what would occur in a random model. Gius and Hylan (1996), in a statistical study of the determinants of baseball player salaries, use a fixed-effects multivariate regression model to estimate player salaries during the 1965 to 1992 period. They conclude that the bargaining power derived from free agency and salary arbitration is a major determinant of a baseball player's salary.

In a study of the home-field advantage, Morong (2004) analyzes the home-field advantage for each season from 1901-2003. He finds that, on average, a home-field advantage exists but that the advantage has gradually and slightly decreased over the century. The average yearly difference between the proportion of games won by the home team and the proportion of games won by the visiting team during the 1901 to 1950 period was .091, while the average yearly difference during the 1951 to 2002 period was .076.

Birnbaum (2004, p. 973) notes that the question of why the home-field advantage exists is one of the largest unresolved issues in sabermetric research. He postulates that there are several possible reasons for the existence of the advantage: 1) the stress of travel makes the visiting teams worse; 2) the support of the crowd lifts the home team to perform better; 3) the home team gains an advantage from batting last; and 4) the physical and psychological benefits associated with players being more comfortable in their home city favors the home team.

A team's likelihood of winning a game is positively related to the number of runs it scores. A plethora of literature has attempted to derive quantifiable measures that explain the run production of particular players or particular teams. Lindsey (1963) estimates a formula where the number of runs a team scores is a function of the four components of its hitting production; singles, doubles, triples, and home runs.[3] Lindsey's model is a forerunner to the modern Linear Weights System that is often used in sabermetrics. These models estimate runs scored as a linear function of the various aspects of a batter getting on base and then advancing once he reaches base. In addition to the four hit-related variables in the Lindsey model, factors such as walks, hit by pitch, stolen bases, and caught stealing are also included in the Linear Weights models (see Palmer and Thorn, 2004). The underlying premise of the Linear Weights System is that teams that are more successful at putting runners on base and advancing them will score more runs. On average, over the course of a season, high-scoring teams win more games than low scoring teams,[4] and during a particular game a team is more likely to win the game as its run production increases.

THE DATA AND DESCRIPTIVE STATISTICS

The data used in this study are from all 2,428 games played during the 2004 Major League Baseball (MLB) season. The data were obtained from the box scores posted on the Major League Baseball website (http://www.mlb.com). For each game, data on 14 hitting and base-running related variables for each team were collected.[5] Data indicating whether a team was the home team or the visiting team, and whether the team traveled to arrive at the first game of a series, were also collected.

Table 1 indicates that during the 2004 season home teams won 53.5 percent of the games played. Overall, home teams won 170 more games than visiting teams. A detailed examination of Table 1 indicates that 26 of the 30 teams won more games as the home team than as the visiting team; seven teams won at least 10 more games as the home team than as the visiting team; five teams had a winning record as the home team but a losing record as the visiting team; and no team had a losing record as the home team but a winning record as the visiting team.

Table 1: Home Wins, Home Losses, Visiting Wins, Visiting Losses, and Home-Field Advantage

Team	Home W	Home L	Visiting W	Visiting L	HF Adv
Anaheim	45	36	47	34	-.0247
Arizona	29	52	22	59	.0864
Atlanta	49	32	47	34	.0247
Baltimore	38	43	40	41	-.0247
Boston	55	26	43	38	.1481
Chicago (NL)	45	37	44	36	-.0012
Chicago (AL)	46	35	37	44	.1111
Cincinnati	40	41	36	45	.0494
Cleveland	44	37	36	45	.0988
Colorado	38	43	30	51	.0988
Detroit	38	43	34	47	.0494
Florida	42	38	41	41	.0250
Houston	48	33	44	37	.0494
Kansas City	33	47	25	57	.1076
Los Angeles	49	32	44	37	.0617
Milwaukee	36	45	31	49	.0569
Minnesota	49	32	43	38	.0741
Montreal	35	45	32	50	.0473
New York (NL)	38	43	33	48	.0617

Table 1: Home Wins, Home Losses, Visiting Wins, Visiting Losses, and Home-Field Advantage					
Team	Home W	Home L	Visiting W	Visiting L	HF Adv
New York (AL)	57	24	44	37	.1605
Oakland	52	29	39	42	.1605
Philadelphia	42	39	44	37	-.0247
Pittsburgh	39	41	33	48	.0801
St. Louis	53	28	52	29	.0123
San Diego	42	39	45	36	-.0370
San Francisco	47	35	44	36	.0232
Seattle	38	44	25	55	.1509
Tampa Bay	41	39	29	52	.1545
Texas	51	30	38	43	.1605
Toronto	40	41	27	53	.1563
All Teams	1299	1129	1129	1299	.0700

Notes: The home-field advantage is the difference between the proportion of games won as the home team and the proportion of games won as the visiting team.

Table 2 lists and defines the variables used in this study. Some variables that aren't included in the regressions are listed because they are used to calculate a variable that is included in the regressions. Table 3 reports the means and standard deviations of the variables included as explanatory variables in the regressions. They are reported for the entire sample of 4,856 observations, as well as separately for home teams, visiting teams, teams that traveled to the first game of a series, and teams that did not travel to the first game of a series. In comparing the means of the home teams to those of the visiting teams, only five of the variables have a difference that is statistically significant at the .05 level. Both OBP and SLG have a larger mean for home teams than for visiting teams, while Singles, SO and GIDP all have a larger mean for visiting teams. To the extent that OBP and SLG promote scoring while SO and GIDP reduce scoring, these differences suggest that home teams score more runs than visiting teams. In comparing the means for traveling teams to those for non-traveling teams in the first game of a series, only the mean of Singles and SO have a difference that is statistically significant at the .05 level. Since Singles and strikeouts (SO) are relatively minor determinants of runs,[6] and since the difference between the means is relatively small, this suggests that the number of runs scored by traveling teams is likely to be approximately equal to the number of runs scored by non-traveling teams.

Table 2: Variable Definitions

Variable	Definition
Runs	The number of runs scored by the team
At-Bats	The number of times the team's hitters officially batted.
Hits	The team's number of hits
Singles	The team's number of one-base hits
Extra	The team's combined number of two-base hits and three-base hits
HR	The number of home runs hit by the team
BBHBP	The number a times the team's batters reach base on a walk or on a hit-by-pitch
SB	The team's number of stolen bases
CS	The number of times a team's runners are caught stealing
Net Steals	The team's number of stolen bases minus its number of caught stealing
GIDP	The number of times the team ground into a double or triple play
SH	The number of times the team advanced a runner with a sacrifice bunt
SF	The number of times the team scored a run with a sacrifice fly
OBP (1)	The team's on-base-percentage
Total Bases (2)	The team's number of total bases
SLG (3)	The team's slugging percentage
Home	A dummy variable that takes a value of 1 if the team is the home team, 0 if not
OneRun	A variable that takes a value of 1 if the run differential in the game is 1 run, 0 if not
Home*OneRun	An interactive term, Home multiplied by OneRun
Travel	A variable that takes a value of 1 if the game is the first scheduled game of a series and the team had to travel to arrive at the game, 0 if not
Home*Travel	An interactive term, Home multiplied by Travel

Notes: (1) OBP is calculated as (Hits + BBHBP)/(At Bats + BBHBP + SF)
(2) Total bases is calculated as (Hits + Two-base hits + (Three-base hits*2) + (Home Runs*3))
(3). SLG is calculated as (Total Bases)/(At bats + SF)

Table 3: Means and Standard Deviations of Selected Variables by Team Classification					
Variable	All	Home	Visitor	Travel	Non-Travel
Runs	4.814	4.829	4.798	4.913	4.837
	(3.218)	(3.122)	(3.312)	(3.252)	(3.139)
Singles [a, b]	6.024	5.925	6.124	6.124	5.780
	(2.729)	(2.671)	(2.783)	(2.746)	(2.503)
Extra	2.022	2.002	2.041	2.023	1.944
	(1.514)	(1.503)	(1.525)	(1.512)	(1.532)
HR	1.123	1.117	1.129	1.184	1.192
	(1.133)	(1.117)	(1.150)	(1.178)	(1.178)
BBHBP	3.722	3.785	3.658	3.724	3.788
	(2.275)	(2.295)	(2.255)	(2.206)	(2.461)
SO [a, b]	6.554	6.239	6.869	6.718	6.156
	(2.762)	(2.713)	(2.775)	(2.841)	(2.815)
Net Steals	.307	.313	.300	.308	.359
	(.948)	(.941)	(.956)	(.960)	(.953)
GIDP [a]	780	.747	.813	.783	.817
	(.858)	(.845)	(.870)	(.827)	(.878)
SH	.356	.360	.353	.361	.323
	(.613)	(.615)	(.611)	(.623)	(.579)
OBP [a]	.328	.334	.322	.327	.330
	(.083)	(.084)	(.081)	(.083)	(.086)
SLG [a]	.419	.427	.411	.421	.429
	(.156)	(.159)	(.153)	(.158)	(.163)
Total Bases	14.742	14.590	14.895	15.080	14.655
	(6.442)	(6.202)	(6.672)	(6.662)	(6.357)
Observations	4856	2428	2428	1095	449

Table 3: Means and Standard Deviations of Selected Variables by Team Classification
Notes: Standard deviations are shown in parenthesis. [a] indicates there is a statistically significant difference at the .05 level between the mean value of home teams and visiting teams [b] indicates there is a statistically significant difference at the .05 level between the mean value of traveling teams and non-traveling teams
The team classifications are defined as follows: All includes all teams in all games played. Home includes only the home team in all games played. Visiting includes only the visiting team in all games played. Travel includes the traveling team(s) in the first scheduled game of a series. Non-Travel includes the non-traveling team, if any, in the first scheduled game of a series.

A LOGIT MODEL TO ESTIMATE THE PROBABILITY OF A TEAM WINNING A GAME

To further examine the effect that the home-field advantage, team batting performance, and travel have on the probability of a team winning a game, a series of five logit regressions are estimated. The dependent variable is a dummy variable that indicates whether a team wins or loses a particular game. Several factors that are likely to affect the probability of a team winning a game have already been discussed. Additionally, an analysis of the 2004 win-loss record of home teams reveals that home teams have a substantially higher probability of winning a game when the run differential between the winning team and losing team is one run than when the differential is more than one run.[7] To account for this phenomenon, in addition to the previously discussed factors the regressions also include as an explanatory variable a dummy variable that indicates whether or not a game is won by one run.

The logit regressions estimated in this study are of the general form,

$$(1) \qquad \ln [P(\mathbf{WIN}) / (1- P(\mathbf{WIN}))] = \alpha + \beta \mathbf{X}$$

The logit regressions [8] are estimated using data from the 2,428 major league regular-season games that were played during the 2004 season. Since two teams participated in each game, this yields 4,856 observations. **WIN** is a dummy variable that takes a value of 1 if a team wins the game and a value of 0 if it loses. **X** is a vector of variables that are hypothesized to affect a team's probability of winning a particular game. The α and β terms represent the intercept and slopes, respectively.

Rearranging (1), the probability of a team winning a randomly selected game, P(WIN), is computed as,

$$(2) \qquad P(WIN) = (1 + e^{-(\alpha+\beta X)})^{-1}$$

Equation (2) allows one to determine the probability of a team winning a game under various scenarios. For example, one can determine the probability that a team will win a game if the game is won by one run, if the team in question scores four runs, if the team is the home team, and if the team did not travel to the game, by simply inserting the appropriate values into the **X** vector. Along these lines, one can determine the probability that a team will win a particular game for any chosen scenario.

THE RESULTS OF THE LOGIT REGRESSIONS

Table 4 reports the results of five versions of equation (1). The most basic version of equation (1), Model 1, includes only Runs and Home as independent variables. In expanded versions of equation (1), two interaction terms, Home*OneRun and Home*Travel are included as explanatory variables. The Home*OneRun interaction term is included to account for the possibility that the likelihood of the home team winning a game is different in games won by one run than in games won by more than one run. The Home*Travel interaction term is included to account for the possibility that the likelihood of the home team winning a game is different in games to which the home team traveled than in games where it did not travel.

Table 4: Results of Logit Regressions with Win as the Dependent Variable, Expanded Model

Variable	Model 1	Model 2	Model 3	Model 4	Model 5
Runs	.5436 [a]	.5538 [a]	5538 [a]		
	(32.862)	(33.060)	(33.055)		
Singles				.2047 [a]	
				(15.180)	
Extra				.3365 [a]	
				(14.087)	
Home Runs				.6358 [a]	
				(18.839)	
OBP					11.4498 [a]
					(16.523)
SLG					4.5812 [a]
					(13.247)

Table 4: Results of Logit Regressions with Win as the Dependent Variable, Expanded Model

Variable	Model 1	Model 2	Model 3	Model 4	Model 5
BBHBP				.1999 [a]	
				(12.406)	
SO				-.1068 [a]	
				(8.314)	
Net Steals				.1874 [a]	.2033 [a]
				(5.195)	(5.488)
GIDP				-.3019 [a]	-.3867 [a]
				(7.309)	(9.102)
SH				.3498 [a]	.2664 [a]
				(6.060)	(4.469)
Home	.3715 [a]	.1115	.1205	.1454	-.0586
	(5.258)	(1.428)	(1.376)	(1.756)	(.681)
Home*OneRun		.8816 [a]	.8811 [a]	.5872 [a]	.7768 [a]
		(7.994)	(7.988)	(5.459)	(6.906)
Travel			.0072	.0005	.0106
			(.066)	(.005)	(.101)
Home*Travel			-.0575	-.0214	-.0175
			(.313)	(.124)	(.096)
Observations	4856	4856	4856	4856	4856
Log Likelihood	-2426.30	-2393.55	-2393.49	-2635.29	-2472.04
Num. Correct [b]	3645	3668	3668	3520	3612

Notes

The absolute values of the t-statistics are shown in parenthesis.

The regressions were run with a constant term, the results of which are not reported here

[a] denotes statistically significant at the .05 level or higher

[b] denotes the number of correct predictions. If the predicted probability for a team exceeds .5, the team is the predicted winner of the game.

As expected, the regression results indicate that the number of runs a team scores has a statistically significant effect on the probability that it will win the game. Model 1 also supports the hypothesis that a home-field advantage exists in major league baseball games.

Beginning with Model 2, the Home*OneRun interaction term is included in the regressions. When the Home*OneRun interaction term is added to the model, the effect of the Home variable becomes statistically insignificant. The interaction term, on the other hand, is highly significant and positive, indicating that the probability of a team winning a game is higher for the home team than the visiting team only when the game is won by one run. This is an important finding since it reveals that a home-field advantage exists only in games that are won by a single run; in games that are won by more than one run there is no home-field advantage.

The effect of travel is determined beginning with Model 3. The regression results reveal that travel is statistically insignificant, indicating that travel does not affect a team's probability of winning a game.[9] The initial expectation was that traveling to the first game of a series would adversely affect a team's likelihood of winning the game, due to factors such as travel-induced stress and fatigue. An interaction term between the home dummy variable and the travel dummy variable, Home*Travel, is included to examine the possibility that the effect of travel on the probability of winning a game is different for home teams than for visiting teams. The regression results reveal that this variable is also statistically insignificant, which indicates that travel does not affect the home team's probability of winning a game differently than the visiting team's probability.[10]

The marginal effects on the probability of winning a game for each of the variables included in the logit models are reported in Table 5. The marginal effect from Model 1 indicates that a home team's probability of winning a game is .0925 larger than that of a visiting team when the run differential is ignored. When the run differential is considered, though, the marginal results indicate that the probability of a home team winning a game is about .22 higher when the game is won by one run than when it is won by more than one run. The marginal results also indicate that by scoring one run more than the average, a team's probability of winning a game increases by about .14.

Table 5: Marginal Effects on the Probability of Win=1

Variable	Model 1	Model 2	Model 3	Model 4	Model 5
Runs	.1353 [a]	.1379 [a]	.1379 [a]		
Singles				.0511 [a]	
Extra				0841 [a]	
Home Runs				.1589 [a]	
OBP*100					.0286 [a]
SLG*100					.0115 [a]
BBHBP				.0500 [a]	

Table 5: Marginal Effects on the Probability of Win=1					
Variable	Model 1	Model 2	Model 3	Model 4	Model 5
SO				-.0267 [a]	
Net Steals				.0468 [a]	.0508 [a]
GIDP				-.0754 [a]	-.0967 [a]
SH				.0874 [a]	.0666 [a]
Home	.0925 [a]	.0278	.0300	.0363	-.0146
Home*OneRun		.2196 [a]	.2194 [a]	.1467 [a]	.1942 [a]
Travel			.0018	.0001	.0027
Home*Travel			-.0143	-.0054	-.0044
Notes: [a] denotes statistically significant at the .05 level or higher in the logit regression					

To determine the relationship between a team's probability of winning a game and the number of runs it scores, we insert the regression coefficients of Model 2 into equation (2) and solve. Table 6 reports the probability of a team winning a game based on the number of runs it scores for three categories of teams: the home team in games won by one run; the home team in games won by more than one run; and the visiting team. Several interesting results emerge. In low scoring games (1 or 2 runs), the probability that the home team wins the game is more than twice as large as that of the visiting team if the game is won by one run. In moderately low scoring games (3 or 4 runs), the probability of the home team winning the game is at least 60 percent larger than for the visiting team if the game is won by one run. In games where the number of runs scored is slightly above the season average of 4.81 runs (5 or 6 runs), the probability of the home team winning the game is at least 25 percent larger than for the visiting team if the game is won by one run.[11] In all cases, when the game is won by more than one run the probability of a home team winning a game is only minimally higher than that of the visiting team.

Table 6: Probability of Winning a Game, by Runs and Team Category, Model 2			
Runs	Home, 1RD	Home, 2RD	Visiting
1	.2371	.1140	.1032
2	.3510	.1830	.1669
3	.4848	.2804	.2584
4	.6208	.4040	.3775

Table 6: Probability of Winning a Game, by Runs and Team Category, Model 2

Runs	Home, 1RD	Home, 2RD	Visiting
5	.7401	.5412	.5134
6	.8321	.6723	.6473
7	.8961	.7812	.7615
8	.9375	.8613	.8475
9	.9631	.9153	.9063
10	.9785	.9495	.9439
11	.9875	.9703	.9670
12	.9928	.9827	.9807
13	.9958	.9900	.9888
14	.9976	.9942	.9936
15	.9986	.9967	.9963

Notes:
Home, 1RD denotes the home team in a game where the run differential is one run.
Home, 2RD denotes the home team in a game where the run differential is two or more runs.
Visiting denotes the visiting team in a game, without respect to the run differential.

The concept of the Linear Weights System (Palmer and Thorn, 2004) is also incorporated into equation (1). The essence of the Linear Weights System is that the number of runs a team scores in a game is determined by its ability to get runners on base and by its ability to advance the runners once they reach base. To incorporate this concept into the model, two regressions, in which the Runs variable is replaced with a set of variables that measure the ability of the team to get runners on base and to advance the runners, are estimated.

The results of these regressions are reported in Table 4 and are listed as Model 4 and Model 5. The variables that measure the team's ability to get runners on base and to advance runners (i.e., performance variables) all have the expected effect. The results of the variables related to the home-field advantage, the effect of travel, and the effect of a game being won by one run are consistent with the previous regressions. The performance variables that have a positive and statistically significant effect on the probability of a team winning a game are Singles, Extra, Home Runs, OBP, SLG, BBHBP, Net Steals, and SH. The variables that have a negative and statistically significant effect on the probability of a team winning a game are SO and GIDP. These results suggest that teams that are more successful at getting runners on base and then advancing the runners during a game are more likely to win the game than teams that are less successful at doing so.

As in Model 1-3, Home is statistically insignificant in Models 4-5, indicating that there is no home-field advantage, per se.[12] The interactive term, Home*OneRun, is again positive and statistically significant, indicating that the home team has an advantage over the visiting team only in games that are won by one run; in games that are won by more than one run there is no home-field advantage. Consistent with the results of Model 3, the two travel-related variables are statistically insignificant, indicating that travel does not affect the probability of either the home team or visiting team winning a game.

The marginal effects of the variables in Models 4-5 are reported in Table 5. The probability of a home team winning a game that is won by one run is between .15-.19 larger than that of the visiting team. This result is not trivial, given that 639 of the 2,428 games (26.3% of the games) played during the 2004 season were won by one run. A typical team then played approximately 43 games that were won by only one run. If the probability of the home team winning such games is between .15 and .19 higher than for the visiting team, it suggests that home teams would be expected to win 24 or 25 of the 43 games while visiting teams would only be expected to win 17 or 18 of the games.

SUMMARY AND CONCLUDING REMARKS

The primary purpose of this paper has been to expand sabermetric knowledge by examining the effect of the home-field advantage on a team's probability of winning a major league baseball game. Although it is commonly believed that the home team has a substantial advantage in major league baseball games, the home-field advantage is an aspect of baseball that has largely been ignored in prior research. Birnbaum (2004, P.973) noted that although historically home teams have won about 54 percent of their games, the question of why they enjoy such an advantage "is one of the largest unresolved issues in sabermetric research."

While a simple analysis of the data that focuses only on the number of wins and losses by home teams and visiting teams supports the contention of a home-field advantage, a more sophisticated analysis indicates that a home-field advantage actually exists only in very close games. In fact, the regression results in this paper indicate that there is virtually no difference between the probability that the home team will win a game and the probability that the visiting team will win the game when the game is won by more than one run. Since about 26 percent of the games played during the 2004 season were won by one run, the results of this study imply that a home-field advantage exists in only about one-quarter of major league baseball games. The results further indicate that the home team advantage in games won by one run is much larger than the eight-percentage point advantage implied by a simple analysis of the data.

The major finding of this study is that the home-field advantage in major league baseball is much more limited than is commonly believed. Rather than existing across all types of games, the home-field advantage exists only in very close games. In games that are decided by more than one run, the home team and visiting team are equally likely to win the game. This paper, has furthered our understanding of the home-field advantage and, as such, has begun to resolve what Birnbaum (2004, p.973) states is one of the largest unresolved issues in sabermetric research. The next step in further resolving the issue should be to examine in more detail differences in games won by one run and games won by more than one run to see if these differences explain why the home team is so much more successful in the games won by one run. This might involve an inning-by-inning analysis of a sample of baseball games to determine if some specific situation that gives the home team the advantage arises predominately in game won by one run. If so, then this would explain why home teams are much more successful in games won by one run than in games won by more than one run.

ENDNOTES

1 There were only two cases where the first place team in a division won at least 13 more games than the second place team. In 2004, the first place St. Louis Cardinals won 13 more games than the second place Houston Astros in the National League's Central division. In 2003, the first place San Francisco Giants won 15 more games than the second place Los Angeles Dodgers in the National League's West division (Major League Baseball website, http://www.mlb.com).

2 In major league baseball, unlike most other professional sports, two teams generally play several games against each other over consecutive days. Typically, three or four games are played over a three or four day period. Of the 2,428 games played during the season, 772 were the first scheduled game of a series. The home team traveled to 328 of these games.

3 Lindsey's formula is Runs = .41(1B) + .82(2B) + 1.06(3B) + 1.42(HR), where Runs is the number of runs scored, 1B is the number of one-base hits, 2B is the number of two-base hits, 3B is the number of three-base hits, and HR is the number of home runs. The formula measures the contribution of each type of hit to a team's run production.

4 We ran a regression, using data from the 1990-2004 seasons on all major league teams, where the number of games a team won during the season was regressed on the number of runs it scored and the number of runs it allowed during the season. The results indicate that the number of runs a team scores during a season positively and significantly affect the number of games it wins. The results of the regression are not reported here.

5 The 14 variables collected are at-bats, runs, hits, walks (BB), strikeouts, two-base hits, three-base hits, home runs, sacrifice hits, sacrifice flies, ground into double or triple plays, stolen bases, caught stealing, and hit by pitch (HBP).

6 We ran an OLS regression using the dataset utilized in this study, with runs scored by a team as the dependent variable. We find that an additional single in a game induces a team to score an extra .5 runs while an additional strikeout reduces the number of runs it scores by .07. Since the difference in mean singles and strikeouts are .34 and .56, respectively, this implies a difference of about .13 runs between a team that travels and a team that does not travel, a relatively small difference. The full results of the regression are not reported here.

7 There were 639 games during the 2004 season where the run difference between the winning and losing team was one run. The home team won 392, or 61.3%, of these games. There were 1,789 games where the run difference exceeded one run. The home team only won 907, or 50.7%, of these games.

8 Discussions of logit models are presented in Aldrich and Nelson (1984), Greene (1997), Pindyck and Rubinfeld (1991), and Ghosh (1991).

9 We also ran regressions where a series of categorical variables related to the distance traveled to arrive at a game replaced the travel dummy variable. Like the travel dummy variable, the effects of the distance variables were statistically insignificant. The results of the regressions are not reported here.

10 To further examine whether or not travel affects the home team, we ran regressions where the sample was home teams in the first game of a series. There were 772 observations in these regressions. These regressions correspond to Models 3-5 reported in Table 4, with the Home, Home*OneRun, and Home*Travel variables excluded. Consistent with the results reported in Table 4, the results indicate that travel does not significantly affect the probability of the home team winning a game. The results of the regression are not reported here.

11 Based on equation (2), the results of Model 2 in Table 6 reveal that a .50 probability of winning a game occurs at 4.90 runs for visiting teams, at 4.70 runs for home teams in a game won by more than one run, and at 3.11 runs for home teams in a game won by one run. This suggests that in games won by one run, home teams need fewer runs, on average, to win than in games won by more than one run.

12 We also ran a two regressions comparable to Models 4 and 5 reported in Table 5 that included the Home variable but excluded the Home*OneRun interaction term. The Home variable was statistically significant and positive at the .05 level in both equations. The same coefficients that were statistically significant in Table 4 were statistically significant in these regressions. The results of these regressions are not reported here.

REFERENCES

Albert, J. (1994). Exploring baseball hitting data: What about those breakdown statistics? *Journal of the American Statistical Association,* 89, 1066-1074.

Albright, S. C. (1993). A statistical analysis of hitting streaks in baseball. *Journal of the American Statistical Association,* 88, 1175-1183.

Aldrich, J. H. & Nelson, F. D. (1984). *Linear probability, logit, and probit models.* BeverlyHills, CA: Sage Publications.

Birnbaum, P. (2004). Sabermetrics. In J. Thorn, et. al. (Eds.), *Total baseball: The ultimate baseball encyclopedia* (8^{th} ed.) (pp. 963-975). Wilmington, DE: Sport Media Publishing.

Ghosh, S. K. (1991). *Econometrics: Theory and applications.* Englewood Cliffs, NJ: Prentice Hall.

Gius, M. P. & T. R. Hylan. (1996). An interperiod analysis of the salary impact of structural changes in major league baseball: Evidence from panel data. In J. Fizel, E. Gustafson, & L. Hadley (Eds.), *Baseball Economics: Current Research.*Westport, CT: Praeger.

Grabiner, D. The sabermetric manifesto. (n.d.) Retrieved on January 17, 2005 from http://www.baseball1.com/bb-data/grabiner/manifesto.html

Greene, W. H. (1997). *Econometric analysis.* Upper Saddle River, NJ. Prentice Hall.

Lindsey, G. (1963). An investigation of strategies in baseball. *Operations Research,* 11, 447-501.

Morong, C. (2004). Historical trends in home-field advantage. *The Baseball Research Journal,* 32, 100-102

Palmer, P., & Thorn, J. (2004). Linear weights. In J. Thorn, et. al. (Eds.), *Total baseball: The ultimate baseball encyclopedia.* (8^{th} ed.) (pp. 976-979). Wilmington, DE: Sport Media Publishing, Inc.

Pindyck, R. S. & Rubinfeld, D. L. (1991). *Econometric models and economic forecasts.* New York, NY: McGraw-Hill.

FUZZY SETS TO FIND A SOLUTION TO SELECT INFORMATION SYSTEMS

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ABSTRACT

An information system selection is strategically important for an organization. However, the review of existing information system selection models for a firm shows that there is a major shortcoming in the previous mathematical models. A goal programming or multiple objective linear programming (MOLP) cannot deal with the organizational differentiation problems. To reduce the complexity in computing the trade-offs among multiple objectives, this paper adopts a fuzzy set approach to solve information system selection problems. A solution procedure is proposed to systematically identify a satisfying selection of possible solutions that can reach the best compromised value for the multiple objectives and multiple constraint levels. The fuzzy solution can help a firm make a realistic decision regarding its information system selection problems as well as the firm's overall strategic issues when environmental factors are uncertain.

INTRODUCTION

Formal planning for an information system selection in a firm is very important because it enables the firm to function more efficiently and effectively given the current dynamic information technological environment. If a firm decides to have a formal planning model, the model first should incorporate economic and professional objectives of their users. In addition, strategic planning is another important factor in information system management (Brancheau & Wetherbe, 1987). However, information system managers, corporate officers, and users may have different perspectives of their information system (Buss, 1983). Therefore, an information system selection for a firm is a complex task and multiple goals are necessary in today's highly competitive business environment.

Linear programming focuses on a single goal -- usually profit maximization or cost minimization -- but this is not the situation for a firm which has multiple information system users and decision makers. A goal programming or multiple objective linear programming (MOLP) cannot deal with the organizational differentiation problems. Since the fuzzy set approach provides a simultaneous solution to a complex system of competing objectives, it seems to be an appropriate tool for solving a firm's information system selection problem. In this paper, a fuzzy set approach to this information system selection problem that incorporates the multiple objectives and multiple decision makers or users of the firm to incorporate multiple constraints will be discussed. The focus of this paper is the fuzziness of objectives or constraints as well as multiple decision maker situations where this fuzzy set approach is the most appropriate solution. The same approach can be used to expand the general information system selection problem. Fuzzy set theory has been applied in business in several areas such as financial planning, inventory management, a variance investigation model, target costing, internal control evaluation model, and capital budgeting problems (see Zebda, 1989; Siegel et al., 1998 for further discussions). Fuzzy set theory can be applied to many business and strategic management problems whenever there is a need to model the imprecise reasoning process of human decision-making. For example, Ruefli and Sarrazin (1981) proposed a fuzzy set approach in strategic control of corporate development in ambiguous situations. Fuzzy set theory should receive more attention in the United States to simplify the modeling of complex business decision-making such as an information system selection. With currently available software, the solution is practical for numerous real world problems. In the following section, prior research is discussed. The third section presents multiple objective information system selection models including a fuzzy solution method. Then, a numerical example with analysis and managerial implications, and conclusions will be addressed.

PRIOR RESEARCH

Today many organizations' successes depend on the appropriateness of their information systems (Ward, 1987). The transformation of the information revolution by significant improvement in cost and performance of the information technology requires strategies for information systems to become an integral part of business strategy formulation. Hayward (1987) proposed a basic planning model for developing an information systems strategy which incorporates management strategy, applications strategy, and technology strategy. However, it is not easy for accounting or MIS managers to justify investing in a new information technology as information technology changes so rapidly (Santos, 1991). Sometimes the benefits of investing in new technologies can be intangible or current capital budgeting techniques are biased against long-term investments by using wrong key assumptions (Hodder & Riggs, 1985). Therefore, effective information system selection decisions require consideration of all benefits to be derived from the project and measurement of these benefits on comparable scales (Ginzberg, 1979). In addition, business performance is required to be measured in multi-dimensional contexts. A traditional return on investment (ROI) or return on sales (ROS) may not be sufficient measures (Zhu, 2000).

Several papers have discussed information system selection problems of a firm. Santhanam et al. (1989) proposed a zero-one goal programming (GP) approach for information system project selection. Their paper incorporated multiple objectives in their model and their model was superior to scoring or ranking methods. However, this GP approach requires that the decision maker(s) must specify goals and priorities in advance (Lee & Kim, 2001). To overcome this limitation, Lee and Kim proposed an integrated approach using Delphi, analytical hierarchy process (AHP), and GP which can reflect interdependencies among criteria and possible information system projects and a group decision making process. Muralidhar et al. (1990) used an AHP process for an information system selection but they did not consider interdependence among criteria. However, the AHP method does not apply to problems having resource feasibility, optimization requirements or project interdependence property constraints (Lee & Kim, p. 112).

Recently, Stewart and Mohamed (2002) proposed an information system projects selection model using multi-criteria utility theory combined with information economics principles based on “business value” and “risk” criteria. However, the ranking of projects based on value and risk can be subjective. Zhang et al. (2003) proposed a neural network approach to predict the success of an information technology project. They found that project management factors are more important than behavioral factors for the success of an information system project.

GP and fuzzy set approach (FSA) are good for solving the multiple-objective problem. Both need an aspiration level for each objective. These aspiration levels are determined by the decision maker (Mohamed, 1997). However, FSA has fussiness in the aspiration levels which are more common in decision making situations. Since goal programming cannot deal with organizational differentiation or multiple decision maker situations in a real world information system selection problem, a fuzzy set approach will be discussed in this paper using a classic example to show that this approach can handle a multiple objective and multiple constraint level information selection problem which is more realistic and practical in a real world situation.

Multiple Objective Information System Selection Model

The review of existing information system selection models shows that a major shortcoming in the previous mathematical models should be addressed. The information system selection planning models set by the goal programming or MOLP approach is an optimal compromise (i.e., trade-off) among several objectives of the corporation. However, it misses other possible optimal compromises of the objectives which result from some linear combinations of objective weights. These compromises lead to different optimal solutions for different decision situations that the corporation may face. In addition, none of the past mathematical models can deal with the organizational differentiation problems. When a firm designs its new information system or modifies its existing information system, the involved decision makers (end users or information system managers) can give different preferences on the same issue, such as the speed of computing capacity or memory capacity. In mathematical models, these different interpretations can be represented by different "constraint levels." Because goal programming or MOLP presumes a fixed single constraint level, the goal programming or MOLP models fail to mathematically describe such an organizational differentiation problem.

To mathematically formulate the multiple-objective information system selection model, let i be the information system in a firm under consideration. Define x_i as the optimum decision variables for an accounting information system and $i = 1, ..., t$. For the coefficients of the objectives, let p_i be the cost savings of information processing, let q_i be the score of decision making flexibility, and let r_i be the ranking of improved planning process. For the coefficients of the constraints, let a_i be cash flow availability for investment, let b_i be system analysts availability, let c_i be programmer availability, let d_i be CPU time availability, and let e_i be resource availability believed by the kth manager for the firm. Here, we allow multiple constraint levels for the cash flow availability for the investment of a new information system that is believed by different managers. Generally, we assume at least two different types of information system managers get involved in the information system selection problems. Then, the multiple objective information system selection model is:

$$\text{Max } \sum_{i=1}^{t} p_i x_i$$

$$\text{Max } \sum_{i=1}^{t} q_i x_i$$

$$\text{Max } \sum_{i=1}^{t} r_i x_i$$

subject to:

$$\sum_{i=1}^{t} a_i x_i \leq (e_1\gamma_j + \ ... + e_t\gamma_k)$$

$$\sum_{i=1}^{t} b_i x_i \leq (e_1\gamma_j + \ ... + e_t\gamma_k)$$

$$\sum_{i=1}^{t} c_i x_i \leq (e_1\gamma_j + \ ... + e_t\gamma_k)$$

$$\sum_{i=1}^{t} d_i x_i \leq (e_1\gamma_j + \ ... + e_t\gamma_k)$$

$$\sum_{j=1}^{k} \gamma_j = 1, \gamma_j \ ? \ 0,$$

$x_i \geq 0$, i = 1, ..., t, j =1,...k. Here t is the double of numbers of objectives because of maximization and minimization solving processes and k is the number of decision makers.

Note that even though this model includes only three specific groups of objectives for presentation purposes, the modeling process easily adapts to all information system selection problems with multiple objectives and multiple constraint levels. We could use an integer LP program for this type of problem to enforce integer solutions that may be easy to interpret and implement for the decision maker.

The proposed model is an LP problem with three objectives and four constraint levels. In the case of cash flow availability for the new investment, multiple constraint level is used. In other words, each manager's belief for the increased cash flow availability for the upcoming year can be different. The differences in the right hand side values are allowed in this model, which allows a group decision-making process. Solving this type of real-world problem is quite a task as market conditions and the firm environment changes. Therefore, this paper proposes a fuzzy set approach to make the computational task as practical as possible.

A FUZZY SOLUTION METHOD

Based on a compromised solution approach for multiple objective decision making problems, Shi and Liu (1993) and Liu and Shi (1994) proposed fuzzy MC linear programming. Their fuzzy approach adopts the compromised solution or the "satisficing solution" between upper and lower bounds of acceptability for objective payoffs. The following section presents the fuzzy set approach for an accounting information system selection problem;

Step 1:

Given the proposed model in this paper, we may use any available computer software to solve the following series of LP problems. For illustration purposes, let's assume t =6 and k =2:

(i) Max (and Min) $\sum_{i=1}^{6} p_i x_i$

subject to:

$$\sum_{i=1}^{6} a_i x_i \leq (e_1\gamma_1 + \ ... + e_6\gamma_2)$$

$$\sum_{i=1}^{6} b_i x_i \leq (e_1\gamma_1 + \ ... + e_6\gamma_2)$$

$$\sum_{i=1}^{6} c_i x_i \leq (e_1\gamma_1 + \ ... + e_6\gamma_2)$$

$$\sum_{i=1}^{6} d_i x_i \leq (e_1\gamma_1 + \ ... + e_6\gamma_2)$$

$$\sum_{j=1}^{2} \gamma_j = 1, \gamma_j ?\ \ 0,$$

and $x_i \geq 0$, for i = 1,..., 6. (1)

(ii) Max (and Min) $\sum_{i=1}^{6} q_i x_i$

subject to: (1). (2)

(iii) Max (and Min) $\sum_{i=1}^{6} r_i x_i$

subject to: (1). (3)

Group (i) of the above LP problems has two types of optimization: one is maximization and the other is minimization. Groups (ii) and (iii) have four problems, respectively. All of them use the same constraints (1). The total number of problems is six. We define the objective value of the maximization problems by $\mathbf{U}_i$ as the upper bound of decision makers' (DM) acceptability for the objective payoff; and the objective value of the minimization problems by $\mathbf{L}_i$ as the lower bound of DMs' acceptability for the objective payoff, i = 1, 2, 3.

Step 2:

Let $f(x)_i$, i = 1, 2, 3, be the objective functions in Step 1. Then, we solve the following linear problem:

Max β

subject to:

$\beta\ (f(x)_i - L_i)/(U_i - L_i),\ i = 1, 2, 3,$

$\beta \geq 0,$

$\sum_{i=1}^{6} a_i x_i £\ (e_1 g_1 + \ ... + e_6 g_2)$

$\sum_{i=1}^{6} b_i x_i £\ (e_1 g_1 + \ ... + e_6 g_2)$

$\sum_{i=1}^{6} c_i x_i £\ (e_1 g_1 + \ ... + e_6 g_2)$

$\sum_{i=1}^{6} d_i x_i £\ (e_1 g_1 + \ ... + e_6 g_2)$

$\sum_{j=1}^{2} g_j = 1,\ g_j \geq\ 0,$

and x_i ³ 0, for i = 1,...,6.

The resulting values of x_j are the fuzzy optimal solution and the value of β is the satisficing level of the solution for the DMs.

The above fuzzy solution method has systematically reduced the complexity of the multiple objective information system selection model because it transforms the multiple objective and multiple constraint LP problem into an LP problem. The above two solution steps can be easily implemented by employing available commercial computer software. In the next section, a numerical example of the information system selection model in a firm will be presented to demonstrate the implications for decision makers.

A NUMERICAL EXAMPLE

A numerical example, which is similar to Santhanam (1989), is developed to present the fuzzy set approach and its solution method. The proposed model in this paper is adopted to compare the fuzzy set approach with the goal programming approach. In the case of our fuzzy set approach, we don't have to specify the priority or preference of goals in advance. In addition, we also allow more than one decision maker's estimated value, such as the amount of investment available for the new information system, as the value in the right-hand side constraint value.

The firm wishes to achieve the following goals. They want to reduce information processing costs, increase flexibility in decision making, and improve the planning process. The total allocated budget for the information system selection is $100,000.

Table 1 contains the information concerning an accounting system selection contribution towards goals. Table 2 contains projected information on resource utilization.

Table 1: Accounting information system contribution towards goals

System #	Cost savings in $	Decision-making Flexibility (score)	Improving planning process (rank)
1	20,000	5	3
2	50,000	5	1
3	10,000	4	2
4	30,000	6	5
5	25,000	2	4
6	15,000	5	6

Table 2: Accounting information system resource utilization				
System no.	Investment in dollars	Number of analysts	Number of programmers	CPU time Required
1	15,000	2	4	10,000
2	80,000	5	6	40,000
3	40,000	1	3	30,000
4	30,000	4	1	10,000
5	25,000	3	3	30,000
6	30,000	2	4	20,000
Resource Availabillity	100,000	6	10	100,000

Analysis

Formulation of the fuzzy set model variables is as follows:

X_i = project number.

Objectives and constraints for the numerical example are as follows:

First, the objective of reducing information processing costs can be expressed as:
Max (Min) Z = $20{,}000X_1 + 50{,}000X_2 + 10{,}000X_3 + 30{,}000X_4 + 25{,}000X_5 + 15{,}000X_6$.

It is desirable to increase flexibility in decision-making and the second objective can be expressed as:

Max (Min) Z = $5X_1 + 5X_2 + 4X_3 + 6X_4 + 2X_5 + 5X_6$.

It is also desirable to improve the planning process and this third objective can be expressed as follows:

Max (Min) Z = $3X_1 + 1X_2 + 2X_3 + 5X_4 + 4X_5 + 6X_6$.

The following are constraints:

(i) Investment cash flow availability

The constraints for the investment cash flow availability for the information system selection (from Table 2) can be expressed as:

$$15{,}000X_1 + 80{,}000X_2 + 40{,}000X_3 + 30{,}000X_4 + 25{,}000X_5 + 30{,}000X_6 \leq 100{,}000.$$

Here the maximum available cash flow for the information system projects is $100,000. One important characteristic of the fuzzy set approach is that it allows more than one right-hand side value. For example, the president thinks that the cash flow available for Project 6 is $40,000. However, the controller thinks that the cash flow available for Project 6 is $30,000. For illustration purposes, only multiple cash flow availability is allowed. To incorporate the multiple criteria (multiple right-hand side values), the constraint for the two different amounts of cash flow availability can be expressed as:

$$X_6 - 30{,}000\gamma_1 - 40{,}000\,\gamma_2 \leq 0.$$

(ii) Number of system analysts available

The constraints for the number of system analysts available can be expressed as:

$$2X_1 + 5X_2 + 1X_3 + 4X_4 + 3X_5 + 2X_6 \leq 6.$$

Here the maximum availability of analysts is 6.

(iii) Number of programmers available

The maximum number of programmers available for this year is 10. This constraint can be expressed as:

$$4X_1 + 6X_2 + 3X_3 + 1X_4 + 3X_5 + 4X_6 \leq 10.$$

(iv) CPU time required

The CPU time required for each information system project development is given in Table 2. The maximum available CPU time for this year is 100,000 seconds. This constraint can be expressed as:

$$10{,}000X_1 + 40{,}000X_2 + 30{,}000X_3 + 10{,}000X_4 + 30{,}000X_5 + 20{,}000X_6 \leq 100{,}000.$$

Finally, Project 6 is the top management's priority to establish a new branch and this constraint can be expressed as: $X_6 = 1$.

A Fuzzy Solution Method

Step 1. The LINDO (Schrage, 1991) computer software was used to solve three maximization problems and three minimization problems for three objectives, respectively. The results are: $U_1 = 55{,}000$, $U_2 = 15$, $U_3 = 12.154$; and $L_1 = 15{,}000$, $L_2 = 5$, $L_3 = 6$.

Step 2. Let β be the satisficing level of the fuzzy optimal solution. Then, we have the fuzzy solution problem as shown in the Appendix. Solving this problem, we obtain: $\beta = 0.92$, which implies 92% of objectives are satisfied with current constraints. The satisfaction rate is high for this numerical example because the problem is simple and well defined. The current solution shows that Projects 1 and 6 should be selected. The original GP solution selected Projects 3, 5, and 6. The difference in the GP solution is that GP sets priorities in their goals. For general GP solutions, they try to satisfy the first goal as much as possible and then satisfy the second goal and so on. In addition, the first goal of the original GP example tries to reduce information processing costs by \$50,000. That is the reason why we reached a different solution here. Finally, $\gamma_1 = 0$ and $\gamma_2 = 1$. This result implies that the controller's opinion dominates the president's opinion. If we force $\gamma_1 \geq 0.3$, the satisfaction rate (β) is 92% and other values are the same. Here $\gamma_1 \geq 0.3$ means that the controller's opinion still dominates the president's opinion. If $\gamma_1 \geq 0.5$, the satisfaction rate is still the same. This case implies that the controller's opinion is equally important as the president's opinion. However, the solutions are the same in this numerical example because the constraint level is narrowly defined.

Managerial Implications

The fuzzy set approach for the information system project selection problem as we discussed in this paper has some managerial implications. First, the model integrates multiple objectives. In this model, multiple constraint levels are also allowed to incorporate each decision maker's preference of new cash flow availability for investments. Second, the fuzzy set approach facilitates each decision maker's participation to avoid suboptimization of a firm's overall goals, which means each decision maker can express their opinions. Third, the fuzzy set approach is flexible enough to easily add more objectives or constraints according to the changing environment. Finally, the fuzzy set approach allows a group decision-making process, which is pretty common in today's business environment, by allowing multiple right-hand side values.

CONCLUSIONS

A fuzzy set approach for an information system project selection model has been developed in this paper. This model can provide a comprehensive scenario about the possible optimal information system selection depending on multiple criteria and multiple constraint levels. In addition, this fuzzy set approach can better handle real-world problems with uncertainty. The fuzzy set model and its solution methods provide better compromised solutions in information system selection problems than the previous linear programming or goal programming models by receiving input from all decision makers.

We can extend the fuzzy set approach to other real-world problems in business. The framework of this model can be applied to other areas, such as financial planning, portfolio determination, inventory management, resource allocation, and audit sampling objectives for a firm if the decision variables and formulation are expressed appropriately.

REFERENCES

Buss, M. D. J. (1983). How to rank computer projects. *Harvard Business Review* 62, 118-125.

Brancheau, J. C. & J. C. Wetherbe (March 1987). Key issues in information systems management. *MIS Quarterly*, 23-45.

Ginzberg, M. J. (1979). Improving MIS project selection. *OMEGA: The International Journal of Management Science*, 7 (6), 527-537.

Hayward, R. G. (1987). Developing an information systems strategy. *Long Range Planning*, 20 (2), 100-113.

Hodder, J. E. & H. E. Riggs (Jan-Feb, 1985). Pitfalls in evaluating risky projects. *Harvard Business Review*, 128-135.

Lee, J. W. & S. H. Kim (2001). An integrated approach for interdependent information system project selection. *International Journal of Project Management*, 19, 111-118.

Liu, Y.H. & Y. Shi (1994). A fuzzy programming approach for solving a multiple criteria and multiple constraint level linear programming problem. *Fuzzy Sets and Systems*, 65,117-124.

Mohamed, R. H. (1997). The relationship between goal programming and fuzzy programming. *Fuzzy Sets and Systems*, 89, 215-222.

Muralidhar K., R. Santhanam, & R. L. Wilson (1990). Using the analytic hierarchy process for information system project selection. *Information and Management*, 18 (1), 87-95.

Ruefli, T. & J. Sarrazin (1981). Strategic control of corporate development under ambiguous circumstances. *Management Science*, 27 (10), 1158-1170.

Santhanam, R., K. Muralidhar, & M. Schniederjans (1989). A zero-one goal programming approach for information system project selection. *OMEGA: International Journal of Management Science*, 17 (6), 583-593.

Santos, B. L. D. (1991). Justifying investments in new information technologies. *Journal of Management Information Systems*, 7 (4), 71-90.

Schrage L. (1991). *User's Manual: Linear, Integer, and Quadratic Programming with Lindo*. San Franscio, California: The Scientific Press.

Siegel, P.H. (ed.) (1998). *Application of Fuzzy Sets and the Theory of Evidence to Accounting II*, Stamford, Connecticut: JAI press Inc.

Shi, Y & Y.H. Liu (1993). Fuzzy potential solutions in multicriteria and multiconstraints levels linear programming problems. *Fuzzy Sets and Systems*, 60, 163-179.

Stewart R. & S. Mohamed (2002). IT/IS projects selection using multi-criteria utility theory. *Logistics Information Management*, 15 (4), 254-270.

Ward, J. M. (1987). Integrating information systems into business strategies. *Long Range Planning*, 20 (3), 19-29.

Zebda A. (1989). Fuzzy set theory and accounting. *Journal of Accounting Literature*, 8, 76-105.

Zhang, G. P., M. Keil, A. Rai, & J. Mann (2003). Predicting information technology project escalation: A neural network approach. *European Journal of Operation Research*, 146, 115-129.

Zhu, J. (2000). Multi-factor performance measure model with an application to fortune 500 companies. *European Journal of Operational Research*, 123, 105-124.

APPENDIX

Maximize β

Subject to:

$20{,}000X_1 + 50{,}000X_2 + 10{,}000X_3 + 30{,}000X_4 + 25{,}000X_5 + 15{,}000X_6 - 40{,}000\beta \geq 15{,}000$

$5X_1 + 5X_2 + 4X_3 + 6X_4 + 2X_5 + 5X_6 - 10\beta \geq 5$

$3X_1 + 1X_2 + 2X_3 + 5X_4 + 4X_5 + 6X_6 - 6.154\beta \geq 6$

$15{,}000X_1 + 80{,}000X_2 + 40{,}000X_3 + 30{,}000X_4 + 25{,}000X_5 + 30{,}000X_6 \leq 100{,}000$

$2X_1 + 5X_2 + 1X_3 + 4X_4 + 3X_5 + 2X_6 \leq 6$

$4X_1 + 6X_2 + 3X_3 + 1X_4 + 3X_5 + 4X_6 \leq 10$

$10{,}000X_1 + 40{,}000X_2 + 30{,}000X_3 + 10{,}000X_4 + 30{,}000X_5 + 20{,}000X_6 \leq 100{,}000$
$X_6 - 30{,}000\gamma_1 - 40{,}000\gamma_2 \leq 0$

$X_6 = 1$

$\gamma_1 + \gamma_2 = 1$

and $\beta \leq 1$.

THE INFLUENCE OF INDIVIDUAL, TASK, ORGANIZATIONAL SUPPORT, AND SUBJECT NORM FACTORS ON THE ADOPTION OF GROUPWARE

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ABSTRACT

Groupware applications such as e-mail, electronic bulletin boards, instant messaging, and computer conferencing are important tools for increasing office communication and productivity, but relatively little is known about the factors involved in choosing to employ this technology. Selected variables from the Technology Acceptance Model were used to form a questionnaire administered to 409 Fortune 500 companies in S. Korea, and results showed that subject norms and individual, task, and organizational factors can be used to predict the use of groupware.

INTRODUCTION

Office workers spend a large amount of their time communicating with others inside and outside of their organization (Long, 1987), and much of this communication is for the purpose of group coordination and collaboration (Mintzberg, 1983). To improve productivity, organizations have turned to computer network-based software that allows individuals who are distributed geographically to work together in a collaborative, computer-based environment (Orlikowski, 1992). This software, called groupware, includes asynchronous tools (e.g., bulletin boards, group calendars, file sharing, and project management) as well as synchronous, real-time applications (e.g., text-based Internet “chatting” and videoconferencing). While some researchers (e.g., Orlikowski & Yates, 1994) include electronic mail as a type of groupware, others (e.g., Coleman, 1997) do not, because it supports primarily person-to-person or person-to-group communication rather that the group-to-group or many-to-many communication so important in computer-supported cooperative work and collaborative computing. To meet this demand for groupware, several software companies have added these applications to their product lines, e.g., IBM (Lotus Notes), Netscape Communications (Collabra Share), Microsoft (Exchange), Novell (Groupwise), FTP Software/Hyperdesk Corp. (GroupWorks), Radnet (WebShare), TeamWare Corp. (TeamWare Office), and the Forefront Group (Virtual Notebook).

Although groupware technology can improve organizational efficiency and effectiveness, many implementations have not met expectations (Nunamaker, 1997). For example, some groupware has failed to be adopted by enough individuals in an organization to make its use beneficial. Other causes for failure include deployment problems where the technology was not available to those who could most benefit from it (Francik, et al., 1991), and a lack of a requirement for those who would not benefit from it to adopt it (Grudin, 1988).

With a modified version of the technology acceptance model (TAM) (Ajzen, 1985) --- used in many prior studies to model the adoption of related, computer-based technologies (e.g., Agarwal & Prasad, 1997; Judy & Hsipeng, 2000; Teo, et al., 1999) --- this study reports on a survey of employees in several, large South Korean companies to expand upon prior research of the factors influencing the adoption of groupware within organizations.

BACKGROUND

Research on the usage behavior of groupware applications is still relatively recent. For example, one study (Van Slyke, et al., 2003) used diffusion of innovation theory to investigate factors that influence adoption of one specific groupware application, Lotus Domino discussion databases. The study showed that intentions to use the application were influenced by perceptions of relative advantage, complexity, compatibility, and result demonstrability, but there were no significant relationships between intentions to use and perceived trialability, visibility, or voluntariness. Another study (Palen, 1997) of two organizations successfully using groupware revealed several technical, behavioral, and organizational factors that enabled initial adoption, and results showed that a set of social and technical factors supported a bottom-up adoption trajectory, leading to a critical mass of users whose subtle peer pressure propelled and subsequently maintained wider use within the organization. Some studies have shown that groupware patterns of adoption can be inconsistent with expectations when there are violations of cost-benefit and task-technology fit criteria (Rao, et al., 1996) and when deployment problems prevent the technology from being available to those who could most benefit from it (Francik, et al., 1991). Finally, other studies (e.g., Ehrlich, 1987; Grudin & Palen, 1995; Markus & Connolly, 1990; Sproull & Kiesler, 1991) have shown that behavior and social conventions affect adoption, a common conclusion being that understanding adoption requires careful examination of the interactions between technological features and the social context of use.

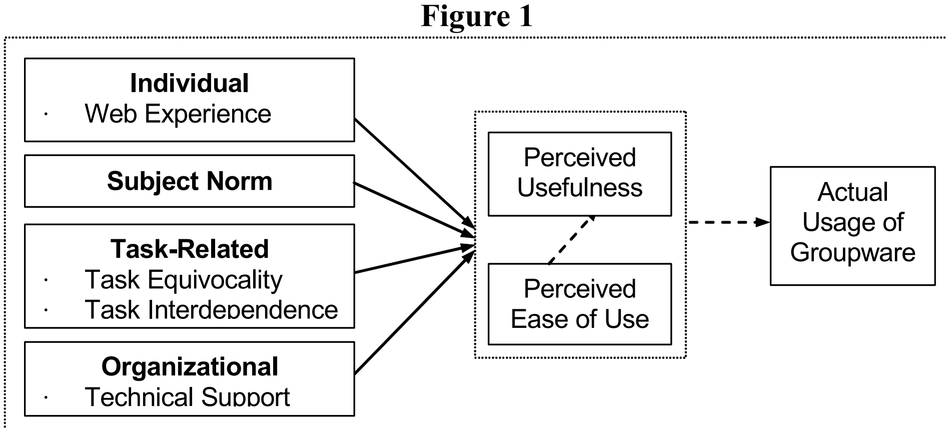
To study the adoption of groupware and other information systems, researchers have used diverse theoretical paradigms (Aarts, et al., 1998), such as the TAM (Davis, 1986), the theory of reasoned action (TRA) (Fishbein & Ajzen, 1975), the theory of planned behavior (TPB) (Ajzen, 1985), diffusion of innovation (DOI) theory (Rogers, 1983), and social cognitive theory (SCT) (Bandura, 1986). Among these theories, the TAM can be used to evaluate systems very early in their development or to assess users' reactions to systems on a trial basis in advance of purchase decisions (Davis, et al., 1989).

The TAM attempts to predict the determinants of individual behavior toward a system, manifested through system utilization. Beliefs about using the system influence intentions to use and behavior via their effect on a potential adopter's attitude. Perceived usefulness captures the extent to which a potential adopter views the innovation as offering value over alternative ways of performing the same task, and ease of use is the degree to which a potential adopter views usage of the target technology to be free of effort (Davis, 1989). Innovations that are perceived to be easier to use and less complex have a higher likelihood of being accepted by users. Perceived ease of use is thought to be a predictor of perceived usefulness which in turn, is believed to have a direct effect on behavioral intentions to use the innovation over and above its influence through attitude. The model postulates that two variables, perceived usefulness and perceived ease of use, have a strong influence on the technology acceptance behaviors of individual users, and the TAM yields highly consistent results for the acceptance behavior of users toward new systems (Adams, et al., 1992; Hendrickson, et al., 1993; Igbaria, et al., 1997; Keil, et al., 1995; Straub, et al., 1995; Straub, et al., 1997). However, some critics (e.g., Bajaj & Nidumolu, 1998; Miller, 1994; Taylor & Todd, 1995) have asserted that the TAM fails to address the effects of social pressure and the influence of workplace environment on the actual usage of information technology.

RESEARCH MODEL AND HYPOTHESES

Our research model is adapted from the works of Davis (1986) that are based on the TBP, DOI, and TRA. The original TAM is modified to avoid the criticism concerning integrating the theory of reasoned action and theory of planned behavior in the original model. To address the criticism that the model fails to address the effects of social pressure and the influence of the workplace environment, our model includes subject norm and task-related factors to examine groupware adoption in a workplace setting. Figure 1 depicts our research model and illustrates the propositions tested in this research.

Figure 1



This paper utilizes 'Web experience' and 'subject norm' to measure the influence of individual factor and social pressure on groupware. Subject norm tests the influence of social pressure on the adoption of groupware application. The model also includes 'task equivocality' and 'task interdependence' to examine the influence of task-related factors, and 'technical support' to test the impact of organizational support.

Individual Factor

Web Experience.

Users' beliefs are determined by individual, job-related, and organizational characteristics. This study adds 'subject norm' to the TAM to measure social pressure for the adoption of groupware. Based on the theoretical model of Zmud (1979), individual characteristics have been reported to play an important role in the eventual success of IS. In addition, the acceptance of computer technology depends on the technology and the level of skill or expertise of the individual using the system (Nelson, 1990). This leads to the study's first hypothesis:

Hypothesis1: The greater the experiences with using the Web, the more likely that users perceive groupware applications are (a) easy and (b) useful.

Subject Norm

Subject norm (also known as social factor, social influence, or social pressure) is an important variable influencing IT usage behavior (Compeau & Higgins, 1995; Hartwick & Barki, 1994; Moor & Benbasat, 1991; Thompson, et al., 1991). This study collects data from an organizational setting in which users may have some social pressure when they use groupware applications. A subject norm refers to the users' perception that their peers think they should or should not perform the behavior. This is related to the intention of using groupware, because users often behave based on their perception of what others think they should do. This leads to the hypothesis:

Hypothesis2: The comprehensions associated with subjective norm are significantly related to the users' perceptions of (a) ease and (b) usefulness on groupware applications.

Task-Related Factors

Task characteristics and their impact on information use are also important to IT adoption (Goodhue, 1995; Goodhue & Thompson, 1995; Igbaria, 1990; Igbaria, 1993). One obstacle to using the TAM has been problems in applying it beyond the workplace. This is because the TAM's fundamental constructs do not fully reflect the variety of users' task environments. The original TAM did not focus on task-related situations because most experiments were conducted with students as subjects, and the lack of task focus in evaluating IT and its acceptance, use, and performance contributed to the mixed results in IT evaluations. This study includes two task-related factors (task equivocality and task interdependence) that may have an impact on groupware adoption.

Task Equivocality

Equivocality is a concept derived by Daft and Macintosh (1981) through their analysis of information processing. This study uses their definition that stresses ambiguity in the interpretation of the message.

> *"Information that is clear and specific and that generally leads to a single, uniform interpretation by users is considered unequivocal. Information that lends itself to different and perhaps conflicting interpretations about the work context is considered equivocal information."* (Daft & Macintosh, 1981, p. 211).

Managers have equivocality when they confuse messages, disagree with others, or lack an understanding of specific work done with co-workers. Equivocality leads the managers to exchange their subjective views within a workplace to define the problem and resolve disagreements, and the presence of equivocality in a workplace can enhance the adoption of groupware.

Task Interdependence

Goldman, et al. (1977) defined task interdependence as the extent to which a task requires organizational units to engage in workflow exchanges of product, information, skills, or resources, and to which actions taken in one unit affect the actions and work outcomes of other units. Task interdependence increases when team members need to integrate their effort with others or need other members' output for their input to do their task. Straus and McGrath (1994) noted that increased levels of task interdependence required greater instances of information exchange needed to clarify task assignments, project requirements, and progress. These arguments lead to the following two hypotheses:

Hypothesis 3: The greater the equivocality of users' tasks, the more likely that users perceive groupware is (a) easy and (b) useful.

Hypothesis 4: The greater the interdependence of users' tasks with others, the more likely that users perceive groupware is (a) easy and (b) useful.

Organizational Support Factor

Technical support

Many researchers have found that organizational support is an important factor in IT usage. Organizational support includes both end-user and management support to use the IT, and the influence of organizational support is related to IT usage (Igbaria, et al., 1995; Igbaria, et al., 1996). Furthermore, lack of organizational support is considered a critical barrier to the effective utilization of computers (Igbaria, 1990). This study utilizes technical support as a type of end-user support, and this factor is one of the widely used external factors in studies examining organizational influence in the adoption of IT. Therefore, this study proposes that technical support is closely related to users' beliefs of usefulness and ease of use of the groupware application.

Hypothesis 5: The greater the level of technical support within an organization, the more likely that users perceive groupware is (a) easy and (b) useful.

Mediators

As the TAM posits that two constructs, perceived usefulness and perceived ease of use, mediate all the external variables likely to influence an individual's decision to adopt IT, this study also utilizes these two constructs as mediating factors between external factors and the actual usage of groupware applications. Studies of IT acceptance during the 1990's reported that perceived usefulness is closely associated with adoption, and perceived ease of use is also directly and indirectly through its effect on perceived usefulness related to IT adoption (Szajna, 1994). Thus, this study also examines the influence of perceived ease of use to perceived usefulness and the influence of these two mediators to actual adoption of groupware applications. Although this study includes two important constructs of the TAM, perceived usefulness and perceived ease of use, the focus of the paper is not on these variables. The results of these tests are also presented in the paper, because the theoretical background of the research model is in the technology acceptance model.

Hypothesis 6: The greater the perception of ease of use with groupware, the more likely that users perceive groupware is useful.

Hypothesis 7: The greater the perception of ease of use with groupware, the more likely the users will actually use the groupware.

Hypothesis 8: The greater the perception of usefulness of groupware, the more likely the users will actually use the groupware.

METHODOLOGY

Instrument Administration

We developed a 29-item questionnaire including four dimensions (17 items) for the independent variables, two dimensions (6 items) for the mediating variables, one item for the dependent variable, and five individual profile items. A seven-point Likert scale is used to elicit responses on the questionnaire. The survey method was adopted to maximize result generalizability by obtaining a statistically testable representation of the various categories of variables, and the mail survey was carefully designed and pilot tested to maximize the response rate. We addressed respondents by name and followed up the undelivered questionnaires by calling individuals. We then mailed a second letter three weeks after the first mailing to remind the respondents. The instruments were reviewed by six IS professionals and pre-tested using 25 professional, evening-MBA students in S. Korea.

The unit of analysis for this research was an individual who worked in a subsidiary or a division of an organization. It should be noted that this study was a part of a larger study of groupware applications adoption. Only items relevant to this study are described here.

Data Collection and Responding Sample Characteristics

Data were collected via a survey questionnaire mailed to 1,500 employees of Fortune 500 companies in South Korea. A total of 409 responses were received, representing a response rate of about 27.3%, and 374 (24.9%) were used for analysis after screening for usability of the questionnaire answers.

The data shows that those in the general management department were using groupware the most (followed by those in information systems and marketing). A total of 127 respondents were in the general management department (34.0% of the total sample). The respondants varied greatly in work experience with 106 out of the 374 respondents having less than five years of work experience, and 92 having five to eight years of experience. Also, 314 (84%) of the respondents had special college or bachelor degrees, 33 had high school degrees, and 23 had master or doctorate degrees. A total of 223 (59.6%) were in the 30 to 39 age range, and 111 (29.7%) were under 30. Of the 374 respondents, 328 were male (87.7%).

ANALYSIS OF STUDY RESULTS

Validity and Reliability of Constructs

Content validity of the survey instrument was established through the adoption of standard instruments, suggestions in the literature, and pre-testing with professionals in the IS field. Construct validity was evaluated by convergent and discriminant validities. Convergent validity is evaluated by measuring the correlation of each item representing the construct with the aggregate measure for that construct less the focal item (Ives, et al., 1983; Kerlinger, 1986). The total score is assumed to be valid when the convergent validity is evaluated. The extent, therefore, to which the item correlates with the total score is indicative of construct validity of the item. All of the correlations shown in Table 1 are positive and significant at the level of 0.001. Discriminant validity is the degree to which a construct differs from other constructs and is usually verified through factor analysis, shown in the last two columns. The columns show factor loadings over 0.5, and the factor number on which each item loaded.

When the Cronbach's alpha coefficient is larger than 0.6, it indicates that internal consistency among the measured items is good (Nunnally, 1978). Reliability or internal consistency, as measured by Cronbach's alpha for all the constructs is strong at 0.74 or above. Tables 2 & 3 show descriptive statistics of the variables, and Table 3 shows reliability and validity analyses of the independent variables.

Table 1. Reliability and validity analysis of variables

Variables (Cronbach's alpha) & Items	Correlation with Total	Factor Loading	Factor Number
Web Experience (alpha = 0.8546)			
WE1 I use Web for various task (Span of Web usage)	.7638	.8483	1
WE2 I visit Website very often (Frequency of Web usage)	.8736	.7511	1
WE3 I use Web very long time (Intensity of Web usage)	.9214	.8057	1
WE4 I know how to use Web search engine	.8407	.8719	1
Subject Norm (alpha = 0.8890)			
SN1 My friends and family affect me a lot in using Internet	.8275	.9320	2
SN2 My colleagues and peers let me use a specific software	.9108	.8618	2
SN3 I feel pressure from management to use a certain IT	.7936	-	
Task Equivocality (alpha = 0.8468)			
TE1 I often have confusion on communication with colleagues	.8738	.7896	4
TE2 I often disagree with my colleagues in group efforts	.8946	.8318	4
TE3 I often do not understand what's going on in my group	.8376	.8027	4

Table 1. Reliability and validity analysis of variables			
Variables (Cronbach's alpha) & Items	Correlation with Total	Factor Loading	Factor Number
Task Interdependence (alpha = 0.8842)			
TI1 I share information with my colleague for my work	.7514	.7924	3
TI2 I use the same resources with my colleagues for my work	.7829	-	
TI3 I need my colleagues' skill to complete my work	.7721	.7767	3
Technical Support (alpha = 0.8798)			
TS1 Company keeps setting advanced IT facilities	.8253	.8720	6
TS2 Company hires extensive technology staffs to help IT users	.8490	.9209	6
TS3 Company keeps advanced Internet security technology	.7754	.7461	6
TS4 Company maintains fast Internet connection	.7439	.7264	6
Perceived Usefulness (alpha = 0.9377)			
PU1 Groupware usage would improve my job performance	.8341	.9223	5
PU2 Groupware usage would enable me to work more quickly	.8138	.9624	5
PU3 Groupware usage would increase my work productivity	.7904	.8531	5
Perceived Ease of Use (alpha = 0.7463)			
PEU1 It would be easy to become skillful at a groupware application	.8874	.8674	7
PEU2 Using a groupware application would be easy	.8548	8449	7
PEU3 Interaction w/ groupware would be clear and understandable	.8176	.7845	7

Table 2. Variable descriptive statistics (N=374)				
Variables	Statistics			
	Minimum	Maximum	Mean	Std. Deviations
Web Experience 1	1	6	4.059	1.523
Web Experience 2	1	7	4.324	1.776
Web Experience 3	1	7	4.195	1.424
Web Experience 4	1	7	5.206	1.448
Subject Norm 1	1	7	5.012	1.343
Subject Norm 2	1	7	5.334	1.196
Subject Norm 3	1	7	3.416	1.433
Task Equivocality 1	1	7	4.348	1.394
Task Equivocality 2	1	7	4.549	1.276
Task Equivocality 3	1	7	4.682	1.358

Table 2. Variable descriptive statistics (N=374)				
Variables	Statistics			
	Minimum	Maximum	Mean	Std. Deviations
Task Interdependence 1	1	7	5.321	1.293
Task Interdependence 2	1	6	3.395	1.465
Task Interdependence 3	1	7	4.933	1.546
Technical Support 1	1	7	3.896	1.643
Technical Support 2	1	7	4.172	1.632
Technical Support 3	1	7	4.567	1.618
Technical Support 4	1	7	4.289	1.685
Perceived Usefulness 1	1	7	4.984	1.378
Perceived Usefulness 2	1	7	4.917	1.383
Perceived Usefulness 3	1	7	4.933	1.406
Perceived Ease of Use 1	1	7	4.913	1.271
Perceived Ease of Use 2	1	7	4.897	1.214
Perceived Ease of Use 3	1	7	4.373	1.288
Actual Use	1	7	5.429	1.163

Table 3. Summary variable descriptive statistics (N=374)		
Variable	Statistics	
	Mean	Std. Deviation
Web Experience	4.4462	1.5431
Subject Norm	4.5876	1.3244
Task Equivocality	4.5266	1.3429
Task Interdependence	4.5499	1.4348
Technical Support	4.2313	1.6447
Perceived Usefulness	4.9449	1.3892
Perceived Ease of Use	4.7280	1.2278
Actual Use	5.4291	1.1634

Although the study was not aimed at regression-based model fitting, possible dependency relationships between the independent and dependent variables should be examined. Table 4 provides Pearson's correlations between external factors and actual usage of groupware. All correlations were significant at the 0.05 level or better except three correlations. While these correlations should be noted in interpreting the study results, they do not present significant difficulties, as the various variables represent distinct factors from the factor analysis. Furthermore, our emphasis is on preliminary testing of individual associations, rather than on regression-based model fitting.

Table : Pearson correlation matrix for external factors, mediating factors, and actual usage

	WE	SN	TE	TI	TS	PU	PEU	AU
Web Experience	1.00							
Subject Norm	.473**	1.00						
Task Equivocality	.272**	.153*	1.00					
Task Interdependence	.072	.174*	.476**	1.00				
Technical Support	.295**	.276**	.004	.297**	1.00			
Perceived Usefulness	.562**	.368**	.284**	.293**	.312**	1.00		
Perceived Ease of Use	.701**	.350**	.169*	.126*	.329**	.563**	1.00	
Actual Usage	.476**	.265**	.081	.239**	.494**	.338**	.413**	1.00

* Significance < .05 ** Significance < .01

Testing Hypotheses

Multiple linear regression analysis was used to test the eight hypotheses formulated for the study. The external factors – individual factors, subject norm, task-related factors, and organizational support – were regressed on users' perceptions of ease of use and usefulness on groupware.

As shown in the Table 5, the result of the test for Hypothesis 1 supports the contention that Web experience is positively related to the users' perception of ease of use (b=.57, t=7.50, p<.001) and usefulness ((b=.31, t=3.95, p<.001) on groupware applications. The result of the tests for Hypotheses 2 reveals that subject norm is significantly related to the users' perceived ease of use negatively (b=–.13, t=–2.50, p<.017) and does not have a significant relationship with users' perceived usefulness. The tests of Hypotheses 3 and 4 show that task-related factors are related only to perceived usefulness (H3b: b=.16, t=2.64, p<.002; H4b: b=.14, t=2.51, p<.006). Hypothesis 5 testing the relationship of technical support in an organization with users' perceptions reveals that technical support is significantly related to users' perceptions of groupware (H5a: b=.09, t=1.85, p<.031; H5b: b=.25, t=3.51, p<.001). Finally, the test results of Hypotheses 6, 7, and 8 show that users' perceptions of ease of use with groupware applications is significantly associated with perceived usefulness. Both perceptions – perceived ease of use and usefulness – are also positively related to actual usage of groupware applications. The test results of Hypotheses 6, 7, and 8 are consistent with the findings of other studies of information technology adoption.

Table 5: Testing hypotheses on service quality of outsourcing providers				
	Hypotheses	b	T	Prob.
Web Experience → PEU	H1a	0.571	7.496	.001**
Web Experience → PU	H1b	0.313	3.947	.001**
Subject Norm → PEU	H2a	-0.127	-2.491	.017*
Subject Norm → PU	H2b	0.027	0.451	.407
Task Equivocality → PEU	H3a	0.023	0.385	.533
Task Equivocality → PU	H3b	0.158	2.639	.002**
Task Interdependence → PEU	H4a	0.026	0.518	.431
Task Interdependence → PU	H4b	0.142	2.514	.006**
Technical Support → PEU	H5a	0.093	1.851	.031*
Technical Support → PU	H5b	0.246	3.512	.001**
PEU → PU	H6	0.265	3.645	.001**
PEU → Actual Usage	H7	0.169	2.763	.001**
PU → Actual Usage	H8	0.108	1.655	.025*
* Significance < .05 ** Significance < .01				

DISCUSSION

All of the hypotheses except H2b (subject norm to perceived usefulness), H3a (task equivocality to perceived ease of use), and H4a (task interdependence to perceived ease of use) are supported. The support for H1 (Web Experience) is expected since earlier studies have consistently shown that users' experiences have a significant and positive influence on the adoption of new information technology (Igbaria, et al., 1995). Any IT adoption with a previously introduced idea can influence the adoption of the new IT, and prior experience with a product class (e.g., the Web) may lead to greater acceptability of new products (e.g., groupware applications) (Tan & Teo, 2000).

H2 (subject norm) was included in the study because users of groupware applications were expected to be influenced by their colleagues for the kinds of groupware applications they used. When the TAM was used for the study of IT acceptance, the research examined personalized information technology (e.g., personal software and personal computer usage), and thus, the subject norm was not an important factor. However, potential users of groupware can be influenced by their colleagues to work well with their group members. As in prior studies that included subject norm as an external factor (e.g., Agarwal & Prasad, 1997; Compeau & Higgins, 1995; Thompson, et al., 1991), this study also included subject norm. However, results of these studies using this variable have reported inconsistent results. Similarly, our study using this variable reveals interesting results. H2b (subject norm to perceived usefulness) is rejected. This implies that social pressure from management or colleagues is not an important determinant to the users' perceptions of usefulness in groupware adoption; rather, task characteristics are more significant factors that affect users' perceptions of usefulness in groupware adoption (H3b and H4b). The other hypothesis with subject norm (H2a, subject norm to perceived ease of use) shows that subject norm is negatively related to the users' perception of ease of use of a groupware application. This implies that social pressure will cause a negative impact on those who might have found groupware easy to use. Agarwal (2000) reported that mandating technology use against the explicit will of an individual may result in negative consequences; thus, it is better that managers promote voluntary acceptance of information technologies.

Both H3a (task equivocality to perceived ease of use) and H4a (task interdependence to perceived ease of use) are rejected. This implies that the level of ambiguity or information sharing in their group efforts is not significantly related to users' perception of ease of use. In other words, the finding shows that neither task ambiguity nor task interdependence affect users' perceptions of groupware ease of use. H3b (task equivocality to the perceived usefulness) and H4b (task interdependence to perceived usefulness) show that whenever users are ambiguous on their job, they think groupware is useful to help them make clear the misunderstandings on their job and would adopt groupware. When users work with other members in their organization by sharing information and resources, they would adopt groupware to enrich their collaboration. The greater the ambiguity and interdependence of users' tasks, the more likely that users will think groupware is useful for their tasks (Dishaw & Strong, 1999).

Hypothesis H5 (technology support to users' perceptions of groupware) is supported and consistent with similar studies (Igbaria, et al., 1995; Igbaria, et al., 1996; Kim, 1996). Groupware applications often utilize the Internet and/or Web technology with an extensive and complicated network infrastructure; thus, technology support from IT staffs is essential to adopt groupware applications.

The positive result for H6 (perceived ease of use to perceived usefulness) is expected since past studies have consistently shown that users' perceptions of ease of use have a significant and positive influence on the users' perception of usefulness. The support for H7 (perceived ease of use to actual usage of groupware) and H8 (perceived usefulness to actual usage of groupware) are also expected, because earlier studies have shown similar findings that users' perceptions affect IT adoption directly (Gefen & Strab, 2000; Miller, 1994; Taylor & Todd, 1995; Yining & Hao, 2002).

MANAGERIAL IMPLICATIONS

Although the results of this study show that subject norm has a negative relationship with users' perceived ease of use on groupware adoption, this relationship is meaningful and significant. When skills and ability to manage groupware applications are not present, users are willing to listen to others, get help from others, and appreciate pressure from management and colleagues. However, when they know how to use and manage groupware applications better, or think learning groupware is easy, then social pressure affects them negatively. Thus, companies should be careful when they adopt groupware by choosing proper strategies and tactics for different levels of users, because mandating technology use against the explicit will of an individual may result in negative consequences. Managers should promote voluntary acceptance of information technologies (Agarwal, 2000). Users who are novices at groupware should be encouraged by management (H2a) and supported by highly skilled technical staffs (H5a and H5b). Finally, high level users should be classified and managed carefully to promote their use of groupware applications.

Both task equivocality and task interdependence to the perceived ease of use on groupware are not supported (H3a and H4a). This implies that the intensity of ambiguity, misunderstanding, or information and resource sharing in their tasks are not significantly related to users' perception of ease of use. Again, task equivocality and task interdependence do not make groupware easier to use. Groupware adopters are encouraged partially by task characteristics (H3b and H4b), by organizational support (H5), and their own previous experience with similar information technology (H1). Both the task equivocality and the task interdependence to perceived usefulness show that whenever users are confused with their tasks, they think groupware is useful. That is, they perceive that groupware can be used to help them remove task equivocality and to enhance collaboration in their workplace. They would adopt groupware to enhance the clearance of communication and better understanding within their workplace, for perceived usefulness is significantly and positively related to the actual usage of groupware applications. When users work closely with other members in their workplace by sharing information and resources, they would also adopt groupware to enrich their collaboration. The greater the ambiguity and interdependence of users' tasks, the higher the perceptions of users to think groupware is useful for their tasks. This result supports the findings of the Dishaw and Strong (1999) study.

The findings from this study have important implications for researchers and practitioners who are using groupware or are considering adopting the technology. In terms of research, this paper provides further evidence of the appropriateness of using individual factors, task-related factors, organizational support, and subject norm that have been used in prior studies of IT acceptance. When considering adoption of the technology, companies should carefully examine external factors that are significantly related to users' perceptions of groupware. For example, in promoting groupware usage, companies can provide users with more experience in similar applications on the Web and provide better technical support.

CONCLUSION

In this paper, we present the results of a survey of Fortune 500 employees in Korea. Although results of such a survey might not be completely generalizable to organizations in the United States and elsewhere in the world, at least one study (Kim, 1997) has shown that there is a reasonable level of agreement between executives in the United States and Korea on the importance of many key information technology issues.

This study shows that the intention to adopt groupware can be predicted by individual, task-related, and organizational factors, as well as subject norm. However, subject norm, task equivocality, and task interdependence provide only partial support to the prediction. Subject norm has an impact only on users' perceptions of ease of use, and task-related factors have an impact only on users' perceptions of groupware usefulness. Among external factors, Web experience and technical support have significant impacts on users' perceptions of ease of use and usefulness, and these findings are consistent with past literature.

REFERENCES

Aarts, H., Verplanken, B. & van Knippenberg, A. (1998). Predicting Behavior from Actions in the Past: Repeated Decision Making or a Matter of Habit? *Journal of Applied Social Psychology*, 28, 1355-1374

Adams, D., Nelson, R. & Todd, P. (1992). Perceived Usefulness, Ease of Use, and Usage of Information Technology: A Replication, *MIS Quarterly*, 16(2), 227-248.

Agarwal, R. (2000). Individual Acceptance of Information Technologies, in *Framing the Domains of IT Management*, R. Zmud (ed.), Pinnaflex Education Resources, Inc.

Agarwal, R. & Prasad, J. (1997). The Role of Innovation Characteristics and Perceived Voluntariness in the Acceptance of Information Technologies, *Decision Sciences*, 28(3), 557-582.

Ajzen, I. (1985). From Intentions to Actions: A Theory of Planned Behavior, in *Action Control: From Cognition to Behavior*, J. Kuhl and J. Beckmann (eds.), New York: Springer-Verlag, 11-39.

Bajaj, A. & Nidumolu, S. R. (1998). A Feedback Model to Understand Information System Usage, *Information & Management*, 33, 213-224.

Bandura, A. (1986). *Social Foundations of Thought and Action*, Englewood Cliffs, Prentice-Hall.

Coleman, D. (1997). The Evolution of Sustainable Value-Added Communities, *Collaborative Strategies,* October. http://www.collaborate.com/hot_tip/tip1097.html.

Compeau, D. & Higgins, C. (1995). Computer Self-Efficacy Development of a Measure and Initial Test, *MIS Quarterly*, 19(2),. 189-211.

Daft, R. & Macintosh, N. (1981). A Tentative Exploration into the Amount and Equivocality of Information Processing in Organizational Work Units, *Administrative Science Quarterly*, 26, 207-224.

Davis, F. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology, *MIS Quarterly*, 13(3), 319-339.

Davis, F. (1986). *A Technology Acceptance Model for Empirically Testing New End-User Information Systems: Theory and Results*, Doctoral Dissertation, Sloan School of Management, MIT.

Davis, F., Bagozzi, R & Warshaw, P. (1989). User Acceptance of Computer Technology: A Comparison of Two Theoretical Model, *Management Science,* 35(80, 982-1003.

Dishaw, M. & Strong, D. (1999). Extending the Technology Acceptance Model with Task-Technology Fit Constructs, *Information & Management,* 36(1), 9-21.

Ehrlich, S. (1987). Strategies for Encouraging Successful Adoption of Office Communication Systems, *ACM Transactions on Office Information Systems*, 5, 340-357.

Fishbein, M. & Ajzen, I. (1975). *Belief, Attitude, Intention and Behavior: An Introduction to Theory and Research*, Reading, MA: Addison-Wesley.

Francik, E., Rudman, S. E., Cooper, S. & Levine, S. (1991). Putting Innovation to Work: Adoption Strategies for Multimedia Communication Systems, *Communications of the ACM*, 34(12) (December).

Gefen, D. & Straub, D. (2000) The Relative Importance of Perceived Ease of Use in IS Adoption: A Study of E-Commerce Adoption, *Journal of the Association for Information Systems*, 1(8), 1-28.

Goldman, M., Stockbauer, J. & McAuliffe, T. (1977). Intergroup and Intragroup Competition and Cooperation, *Journal of Experimental Social Psychology,* 13(1), 81–88.

Goodhue. D. (1995). Understanding User Evaluations of Information Systems, *Management Science*, 41(12), 1827-1844.

Goodhue, D. & Thompson, R. (1995). Task-Technology Fit and Individual Performance, *MIS Quarterly*, 19(2), 213-236.

Grudin, J. (1988). Why CSCW Applications Fail: Problems in the Design and Evaluation of Organizational Interfaces, *Proceedings of the Conference on Computer-Supported Cooperative Work (CSCW '88)*, Portland, OR, 85-93.

Grudin, G. & Palen, L. (1995). Why Groupware Succeeds: Discretion or Mandate? *Communications of the ACM*, 37(1), 93-105.

Hartwick, J. & Barki, H. (1994). Explaining the Role of User Participation in Information System Use, *Management Science*, 40(4), 440-465.

Hendrickson, A., Massey, P. & Cronan, T. (1993). On the Test-Retest Reliability of Perceived Usefulness and Perceived Ease of Use Scales, *MIS Quarterly*, 17(2),. 227-230.

Igbaria, M. (1990). End-User Computing Effectiveness: A Structural Equation Model, *Omega*, 18(6), 637-652.

Igbaria, M. (1993). User Acceptance of Microcomputer Technology: An Empirical Test, *Omega*, 21(1). 73-90.

Igbaria, M., Guimaraes, T. & Davis, G. (1995). Testing the Determinants of Microcomputer Usage via a Structural Equation Model, *Journal of Management Information Systems*, 11(4), 87-114.

Igbaria, M., Parasuraman, S. & Baroudi, J. (1996). A Motivational Model of Microcomputer Usage, *Journal of Management Information Systems*, 13(1), 127-143.

Igbaria, M., Zinatelli, N., Cragg, P. & Cavaye, A. (1997). Personal Computing Acceptance Factors in Small Firms: A Structural Equation Model, *MIS Quarterly*, 21(3),. 279-305.

Ives, B., Olson, M. & Baroudi, J. (1983).The Measurement of User Information Satisfaction, *Communications of the ACM*, 26(10), 785-793.

Judy, C. & Hsipeng, L. (2000). Towards an Understanding of the Behavioral Intention to Use a Web Site, *International Journal of Information Management*, 20(3), 197-208.

Keil, M., Beranek, P. & Konsynski, B. (1995). Usefulness and Ease of Use: Field Study Evidence Regarding Task Considerations, *Decision Support Systems*, 13(1), 75-91.

Kerlinger, F. (1986). *Foundations of Behavioral Research*, 3d ed. Fort Worth, TX: Holt, Rinehart and Winston.

Kim, H. (1997). Key Issues of IS Management in Korea and a Comparison with the United States, *Proceedings of the Decision Sciences Institute*, 2, November 22-25, San Diego, CA, 542-544.

Kim, I. (1996). *The Effects of Individual, Managerial, Organizational, and Environmental Factors on the Adoption of Object Orientation in U.S. Organizations: An Empirical Test of the Technology Acceptance Model*, Doctoral Dissertation, University of Nebraska.

Long, R. (1987). *New Office Information Technology: Human and Managerial Implications.* New York: Croom-Helm.

Markus, M. & Connolly, T. (1990). Why CSCW Applications Fail: Problems in the Adoption of Interdependent Work Tools, *Proceedings of ACM CSCW'90 Conference*, 371-380.

Miller, M. (1994). *The Extended Technology Acceptance Model: Theory and Empirical Test*, Doctoral Dissertation, Auburn University.

Mintzberg, H. (1983). *The Nature of Managerial Work*. New York: Harper and Row.

Moor, G. & Benbasat, I. (1991). Development of an Instrument to Measure the Perceptions of Adopting an Information Technology Innovation, *Information Systems Research*, 2(3), 192-222.

Nelson, D. (1990). Individual Adjustment to Information-Driven Technologies: A Critical Review, *MIS Quarterly*, 14, 79-98.

Nunamaker, J. (1997).Future Research in Group Support Systems: Needs, Some Questions and Possible Directions, *International Journal of Human-Computer Studies*, 47, 357-385.

Nunnally, J. (1978). *Psychometric Theory*, 2nd Edition, New York: McGraw-Hill

Orlikowski, W. (1992). Learning from Notes: Organizational Issues in Groupware Implementation, *Proceedings of CSCW'92, Conference on Computer Supported Cooperative Work*, 362-369.

Orlikowski, W. & Yates, J. (1994), Genre Repertoire: Examining the Structuring of Communicative Practices in Organizations, *Administrative Science Quarterly*, 39, 541-574.

Palen, L. (1997). *Groupware Adoption and Adaption.* Unpublished Ph. D. dissertation. University of California, Irvine.

Rao, V., McLeod, P. & Beard, K. (1996). Adoption Patterns of Low-structure Groupware: Experiences with Collaborative Writing Software, *29th Hawaii International Conference on System Sciences (HICSS)* Vol. 3: Collaboration Systems and Technology, January 3 - 6, Maui, Hawaii,. 41.

Rogers, E. (1983). *Diffusion of Innovations*, New York,: Free Press.

Sproull, L. & Kiesler, S. (1991). *Connections: New Ways of Working in the Networked Organization*. Cambridge, MA: MIT Press.

Straub, D., Limayem, M. & Karahanna, E. (1995). Measuring System Usage: Implications for IS Theory Testing, *Management Science*, 41(8), 1328-1342.

Straub, D., Keil, M. & Brenner, W. (1997). Testing the Technology Acceptance Model across Cultures: A Three Country Study, *Information & Management*, 33(1), 1-11.

Straus, S. & McGrath, J. (1994). Does Medium Matter? The Interaction of Task Type and Technology on Group Performance and Member Reactions, *Journal of Applied Psychology,* 9(1), 87–97.

Szajna, B. (1994). Software Evaluation and Choice: Predictive Validation of the Technology Acceptance Instrument, *MIS Quarterly*, 18(3), 319-324.

Tan, M. & Teo, T. (2000) Factors Influencing the Adoption of Internet Banking, *Journal of the Association for Information Systems*, 1(5), 1-42.

Taylor, S. & Todd, P. (1995). Understanding Information Technology Usage: A Test of Competing Models, *Information Systems Research*, 6(2), 144-176.

Teo, T., Lim, V & Lai, R. (1999). Intrinsic and Extrinsic Motivation in Internet Usage, *Omega, the International Journal of Management Science*, 27, 25-37.

Thompson, R., Higgins, C. & Howell, J. (1991). Personal Computing: Toward a Conceptual Model of Utilization, *MIS Quarterly*, 15(1),. 125-142.

Van Slyke, C., Lou, H. & Day, J. (2003). Intentions to use groupware: The Influence of Users' Perceptions, *Advanced Topics in Information Resources Management*, Publisher Idea Group Publishing Hershey, PA, .238 - 257

Yining, C. & Hao, L. (2002). Toward an Understanding of the Behavioral Intention to Use a Groupware Application, *Journal of End User Computing*, 14(4), 1-16.

Zmud, R. (1979) Individual Differences and MIS Success: A Review of the Empirical Literature, *Management Science*, 25(10), 966-979.

HEURISTICS FOR SCHEDULING OPERATIONS IN MRP: FLOWSHOP CASE

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ABSTRACT

This paper investigates the issue of operations scheduling for Material Requirements Planning (MRP) Systems. Two general scheduling approaches, namely forward and backward procedures, are proposed to perform operations scheduling in MRP. Moreover, we develop various heuristic scheduling rules for use in the two general scheduling approaches. A simulation experiment is conducted to study the effectiveness of the proposed heuristics under the flowshop case—a manufacturing environment where all jobs processed in the shop must follow the same machine or workstation sequence. Lastly, we present and discuss the computational results obtained from our simulation experiment.

INTRODUCTION

This paper studies the issue of operations scheduling for Material Requirements Planning (MRP) systems under the general discrete manufacturing environment. The general discrete manufacturing is commonly referred to as multi-stage, production-inventory system (MS-PIS). The MS-PIS is important because it is considered as the most common type of production and manufacturing systems (Goyal & Gunasekaran, 1990). In the MS-PIS, each product or part requires one or more operations to be processed at some designated machines. The operations sequence of a product or part has to follow the specifications indicated on its routing sheet. It should be noted that different machines can be used to perform the same operation; however, they may possess different setup times and per unit processing times, as well as different per unit time costs.

MRP is a basic tool for performing the detailed material planning function in the manufacture of component parts and their assembly into finished items (Vollmann et al., 2005). The basic MRP inputs are: (1) master production schedule, (2) bill of materials, and (3) inventory records file; and the basic MRP output consists of a set of detailed schedules indicating, for each part, when and how much to order. In order to generate the output, the MRP logic takes an end-item requirements from the master production schedule and translates them into time-phased requirements for assemblies, parts, and raw materials using the bill of materials offset by lead time given by the inventory records file.

MRP has been a very powerful and pervasive tool adopted by numerous companies for over three decades; nonetheless, it possesses some major drawbacks. Two weaknesses are particularly noteworthy. The first one is the need to set planned lead time (Kanet, 1982; St. John, 1985), which is a very difficult, if not impossible, task. Plossl and Welch (1979) and Huge (1979) found that the waiting time in queue could amount to as much as 95% of the lead time. Hence, lead time is very much determined by how long it takes to obtain the required capacity, that is, the congestion level of the shop. As noted by Karmarkar (1993), from the perspective of MRP the lead time is an attribute of the part, rather than of the condition of the shop. The second noteworthy weakness is about determinating lot size quantity. According to Silver et al. (1998), most MRP systems do not provide support to any lot-sizing rules other than Economic Order Quantity (EOQ) and Lot For Lot (LFL). Even if the support is available, most users seem to rely on simple rules that may generate higher cost than is possible by using other rules.

A number of articles have appeared in the literature to discuss the possible integration of MRP and Just in Time (JIT). Nonetheless, most of them are focused on the conceptual level of the JIT philosophy. Flapper et al. (1991) propose one of the most rigorous frameworks for integrating MRP and JIT. Their three-step process makes use of MRP's backflushing and phantom features, and allows the JIT concepts to be utilized to the fullest extent. Other research in this area includes Benton and Shin (1998), Neely and Byrne (1992), Bose and Rao (1988), Belt (1987), Blackburn (1985), Cook and Muinch (1984), Discenza and McFadden (1988), and Heard (1984).

For analytical studies, Huq and Huq (1994) examine the best conditions on which JIT production techniques can be embedded in an MRP based job shop system and conclude that leveling workload is a key factor to sustain better performance of JIT based job shop production. Ding and Yuen (1991) believe that MRP system itself has a capability of adopting the Kanban production control scheme, and their study focus on evaluating how the modified MRP systems can cope with the coexistence of MRP and Kanban. Chanudhury and Whinston (1990) propose a hybrid control methodology for a flowshop that is decentralized and adaptive in nature. Other research includes Deleersnyder et al. (1992), Betz (1996), and Blackburn (1985). For a recent review on the evolution of MRP and JIT integration, please refer to Benton and Shin (1998).

Ho and Chang (2001) propose a general system which integrates MRP with the pull idea of JIT for the MS-PIS. The integrated system aims at creating an improved production planning and scheduling model by developing a set of detailed shop floor schedules that determine which operation of which part to be processed by which machine at what time and in what quantity. It gets rid of two major problems inherent in MRP: (1) setting planned lead time and (2) lot sizing determination. Moreover, the integrated system resolves the issue of operating on a level schedule in JIT (Karmarker, 1989).

Ho and Chang (2006) formulate a mixed integer programming model to minimize total production cost (TPC) for the integrated system. The TPC consists of three components: processing time cost, setup time cost, and holding cost. The multiple machine routings aspect of the MS-PIS makes it necessary to consider processing time cost in the objective function, since different machines may carry different unit processing times and different setup times. A setup cost is required whenever there is a change of product or part processed in a machine; nonetheless, setup cost is assumed to be sequence independent. Inventory holding cost is imposed on both work-in-process and finished goods. The applications of the mixed integer programming approach unfortunately are limited to small size problems. Therefore, heuristics that can yield good solutions quickly are very desirable.

In this paper, we introduce two general scheduling approaches, namely forward and backward procedures, to perform operations scheduling in MRP. We also develop various heuristic scheduling rules for use in the two general scheduling approaches. Moreover, a simulation study is conducted to evaluate the performance of the proposed heuristics under the *flowshop* environment—a manufacturing environment where all jobs processed in the shop must follow the same machine or workstation sequence. These heuristics have been applied to the jobshop case and reasonable computational results were obtained in Ho and Chang (2005). The flowshop is particularly significant because in many manufacturing and assembly facilities, a number of operations must be done on every job (Pinedo, 2002). Often these operations have to be done on all jobs in the same order implying that jobs have to follow the same route.

The rest of this paper is organized as follows. The next section reviews the integrated system framework by Ho and Chang (2001). In section 3, we introduce the proposed heuristics. Section 4 discusses the design and scope of our simulation study. In section 5, we present the computational results obtained from our simulation study. Lastly, section 6 summarizes and concludes the paper.

SYSTEM FRAMEWORK

Ho and Chang (2001) develop a system which integrates MRP with JIT by incorporating the time phasing and product explosion principles of MRP and the pull concept of JIT. The scheduling logic of the system may be described as follows. A demand of a product or part triggers or pulls the production of the last operation of that item; hence, the last operation needs to be scheduled first. The scheduling of the last operation triggers the need to schedule the immediate preceding or upstream operation. This pull-oriented scheduling process continues until all the necessary operations are scheduled to meet the demand. If the part under consideration is made of other part(s), then the production of the first operation of the part pulls the production of the last operation(s) of its subordinate part(s).

The following example is used to illustrate the pull scheduling logic of their system. Suppose product A consists of one unit of part B and two units of part C, and it requires one operation that can only be processed on machine 5, i.e., M_5. Part B requires two operations: the first operation may be processed on M_1 or M_3; while the second operation can only be processed on M_2. Part C needs one operation and may be processed on M_3 or M_4. A demand for product A, say in period 8, would drive the system to search for the last operation of product A, i.e., the most downstream operation. Since product A requires only one operation, the integrated system could schedule the operation in period 8 or earlier. Assuming that the operation is scheduled in period 8 on M_5, this triggers or pulls the production of parts B and C. The system can now schedule the second operation of part B and the first and only operation of part B in period 7 or earlier. Suppose that operation 2 of part B and operation 1 of part C are scheduled on M_2 and M_4 in periods 7 and 6, respectively. This scheduling triggers the need to schedule operation 1 of part B in period 6 or earlier and suggests that the material requirements for part C be arrived by period 6. Assuming that operation 1 of part B is scheduled on M_3 in period 4, this scheduling requires that we receive the material requirements for part B by period 4.

The major assumptions of the system are as follows. First of all, consecutive operations of a product or part may not be processed in the same period t. In other words, if operation j is processed at time t, then operation $j + 1$ can only be processed at time $t + 1$ or later. Second, the transfer time of a part between machines is assumed to be small enough that a part processed on a machine at time t can arrive at the next machine for processing at time $t + 1$. Third, as a part progresses through additional stages of processing with more value added, its per unit holding cost increases. This assumption helps drive inventory to its least processed form.

THE PROPOSED HEURISTICS

Two general classes of heuristic approaches will be introduced to implement the pull element in operations scheduling for the integrated system. The first general heuristic approach will be called the *backward* procedure. The backward procedure starts at the end of the planning horizon, working backward towards the beginning of the planning horizon; hence, the scheduling process is one-pass. On other words, the scheduling process only has to go from period t to period 1 one time, because all the derived demands are created at time $t - 1$ or earlier. The one-pass characteristic of the backward procedure implies that its operations scheduling order, in terms of time period, is strictly non-increasing.

The second general approach will be called as the *forward* procedure. The main difference between the forward and backward algorithms is that the forward procedure starts at the beginning of the planning horizon, working forward towards the end of the planning horizon. It should be noted that although the forward procedure starts from the beginning of the planning horizon, it still schedules the downstream operation before its corresponding upstream operation(s). Due to the creation of the derived demands for upstream operations, the forward procedure may have to carry on many passes before all demands are satisfied. That is, the operations scheduling order of the forward procedure can increase for a while, then decrease for a while (to schedule the derived demands), and increase again.

The following notation is used to present the proposed scheduling heuristics.

Subscripts:

I	Subscript for parts or products, $i = 1,\ldots, n$.
j	Subscript for operations of part i, $j = 1,\ldots, p_i$, where p_i is the number of operations for part i.
k	Subscript for machines, $k = 1,\ldots, m$.
t	Subscript for time period, $t = 1,\ldots, T$.

Decision variable:

$Q_{ijkt'}$	The quantity of operation j of part i scheduled on machine k at time period t'.

Production time parameters:

P_{ijk}	Unit processing time of operation j of part i if processed by machine k.
S_{ijk}	Setup time of operation j of part i if processed by machine k.
A_{kt}	Capacity availability of machine k at period t.

Demand-related parameters:

D_{it}	The demand (from MPS) for product i in period t.
D_{ijt}	The derived demand for operation j of part i that must be done in time t or earlier.

Cost-related parameters:

C_{kt}	Unit time cost of machine k at period t.
V_{ij}	Unit inventory value of operation j of part i.
H_{ij}	Unit holding cost of operation j of part i for one time period, where $H_{ij} = V_{ij} \bullet r$, where r is the holding cost interest rate.
$U_{ijkt'}$	Unit processing cost of operation j of part i processed by machine k at period t', i.e.,

$$U_{ijkt'} = ((Q_{ijkt'} P_{ijk} + X_{ijkt'} S_{ijk}) \cdot C_{kt'}) / Q_{ijkt'}, \text{ if } Q_{ijkt'} > 0.$$

$Z_{ijkt'}$	Unit total cost (processing, setup, and holding costs) if a particular demand in period t for operation j of part i processed by machine k at period t', i.e.,

$$Z_{ijkt'} = ((Q_{ijkt'}P_{ijk} + X_{ijkt'}S_{ijk}) \cdot C_{kt'} + (t-t') \cdot H_{ij}) / Q_{ijkt'}, \text{ if } Q_{ijkt'} > 0.$$

Both backward and forward procedures were applied to the jobshop case and discussed in Ho and Chang (2005). For clarity, we repeat these procedures here.

Backward Procedure

Step 1	Set $\alpha = \{D_{ijt'} \mid D_{ijt'} > 0$, for i is the end product or part (component) with independent demand, j is the last operation of part i, and for $t' = 1, \ldots, T\}$.
Step 2	Set $t = T$.
Step 3	Get $\beta = \{D_{ijt'} \mid D_{ijt'} \quad \alpha$ and $t' = t\}$.
Step 4	If β = Æ, then go to Step 9, else enter Step 5.
Step 5	For all D_{ijt} in β, use a heuristic criterion to determine $Q_{ijkt'}$, where $t' \le t$. That is, to find how much of which operation of which part to be scheduled in which machine and at what time.
Step 6	Schedule $Q_{ijkt'}$ and update the corresponding D_{ijt} in α and β accordingly.
Step 7	If any predecessor of $Q_{ijkt'}$ exists, then derive the corresponding demand for the immediate predecessor and update it in α.
Step 8	Go to Step 4.
Step 9	Set $t = t - 1$. If $t > 0$, then go to Step 3; otherwise, stop.

Step 1 extracts demand requirements for the last operation of the final products (end items) and parts over the planning horizon, $1,\ldots,T$, and puts them in set α. Step 2 sets the scheduling index t equal to T, so as to trigger the scheduling process from the last time period of the planning horizon. For a particular time period of the scheduling index, t, Step 3 gathers the demand requirements of that time period and places them in set β. Step 4 checks if β = Æ, i.e., any unscheduled demand remaining in time period t. If there is no demand, then the procedure goes to Step 9; otherwise, it enters Step 5. For the demand requirements at period t, Step 5 uses a heuristic criterion to determine the quantity of a particular operation of a particular part to be produced at a particular time period by a particular machine, denoted by $Q_{ijkt'}$ such that $t' \le t$. The proposed heuristic criteria will be presented in Section 3.1. It should be the determination of $Q_{ijkt'}$ is subject to machine capacity, A_{kt}. Step 6 schedules the selected $Q_{ijkt'}$ and updates the not yet scheduled demands in sets α and β for the time period t. Step 7 creates the derived demands if a preceding operation or part exists and updates the derived demands in set α. In Step 8, the procedure goes back to Step 4 and tests if all demands in period t have been scheduled. Finally, Step 9 decrements t by 1 and checks if all time periods are exhausted. If all periods have been considered, i.e., $t = 0$, then the procedure stops; otherwise, it goes to Step 3 and begins scheduling the demands of an earlier period.

The forward procedure is identical to the backward procedure except for the following steps.

Step 2 Set $t = 1$.

Step 9 If $D_{ijt'} =$ Æ for all i, j, and $t' < t$, then go to Step 10; else, let t be the earliest time such that $D_{ijt} \neq 0$, and go to Step 3.

Step 10 Set $t = t + 1$. If $t \leq T$, then go to Step 3; otherwise, stop.

Step 2 sets the scheduling index t equal to 1 implying that it is a forward procedure. In Step 9, if there is no demand in period t or earlier, then the procedure goes to Step 10; otherwise, let t be the earliest time where a demand exists and the procedure returns to Step 3. Finally, Step 10 increments t by 1 and checks if all time periods are exhausted. If all periods have been considered, i.e., $t = T$, then the procedure stops; otherwise, it returns to step 3 and begins scheduling the demand requirements of an earlier period.

Three heuristic criteria are specifically developed for use in the selection of $Q_{ijkt'}$ in Step 5 of the proposed procedures. The first criterion, Z, schedules the batch with the smallest Z first. Hence, Step 5 is Z: For all D_{ijt} in β, select $Q_{ijkt'}$ such that $\min_{t' \leq t}\{Z_{ijkt'}\}$.

Let $LB_{ijkt'}$ be the lowest possible cost of fulfilling demand D_{ijt}, i.e., $LB_{ijkt'} = \min\{P_{ijk} \bullet C_{kt'}\}$. The second criterion, $Z - LB$, schedules the batch with the smallest $Z - LB$ difference first. The smallest difference represents the actual minimum unit cost above the theoretical minimum. Therefore, Step 5 of the proposed procedures may be replaced by *Z-LB*: For all D_{ijt} in β, select $Q_{ijkt'}$ such that $\min_{t' \leq t}\{Z_{ijkt'} - LB_{ijkt'}\}$.

The development of the third criterion, Z/Q, is based on the fact that it should be more desirable to select the batch with the largest Q. This is because a large Q allows the system to derive higher demand for preceding operations early. Hence, Step 5 of the proposed procedures becomes Z/Q: For all D_{ijt} in β, select $Q_{ijkt'}$ such that $\min_{t' \leq t}\{Z_{ijkt'} / Q_{ijkt'}\}$.

Lastly, we propose an alternative selection approach using the three criteria discussed earlier as follows. For *each* of the D_{ijt} in β, we first find the $Q_{ijkt'}$ that corresponds to the smallest $Z_{ijkt'}$, then select the $Q_{ijkt'}$ with the largest $Z_{ijkt'}$. The rationale for this approach is that by choosing the maximum of the minimum $Z_{ijkt'}$, we may be able to avoid the need of paying an even higher premium for satisfying the D_{ijt} later on. Therefore, Step 5 becomes: For *each* D_{ijt} in β, find $Q_{ijkt'}$ using one of the three proposed criteria, then select $Q_{ijkt'}$ with the maximum $Z_{ijkt'}$.

SIMULATION DESIGN

Jobshop and flowshop generally represent two common, but extreme, types of manufacturing environments. Two characteristics are commonly used to distinguish the two shop configurations; they are machine routings and demand patterns. In this paper, we investigate the flowshop manufacturing environment. For the flowshop case, all jobs must follow the same pattern when they go through the production system; hence, multiple routings are not available. However, their setup times and per unit processing times may be different. The demand for the flow-shop is more continuous or stable; that is, there is a relatively small demand fluctuation from one period to the next. In our simulation study, the demand for every product in every time period is assumed to follow the discrete uniform distribution with parameters, 0 and 40, i.e., *DU*(0,40).

The planning horizon for the flow shop case is set at 15 periods. The shop has five machines, and each machine has 500 units of time per period. The shop produces three end-products (with independent demand). Each of the three parts requires five operations, and they must be performed in specified order.

The holding cost is assumed to be a linear function of the number of operations. That is, the WIP after two operations is twice as expensive to hold as the WIP after one operation. Also, the unit machine time cost is assumed to be one and it is the same for all machines. The machine routing is such that all three products go through the same machine for the same stage of production. The per unit processing time for each operation/part is generated from the *DU*(5,25) distribution; while the setup time for each operation/part is generated from the following Discrete Triangular (*DT*) distribution, *DT*(10,50,30),

Two groups of heuristics, nine forward and nine backward heuristics, are evaluated in our simulation study. For each of the two groups of heuristics, we consider six criteria, namely, Z, Z-LB, Z/Q, SUPT (Shortest Unit Process Time), STPT (Shortest Total Process Time), and LFL (Lot For Lot). In addition, we test the Z, Z-LB, and Z/Q criteria using the alternative selection approach described in Section 3.1. We will use *f* and *b* to denote the forward and backward procedures, and *min* and *max* to denote the regular and alternative selection approaches. For example, fmax(Z/Q) refers to the forward procedure with the alternative Z/Q selection criterion.

We study the impacts of two factors, namely demand volume and holding cost, on the proposed heuristics. For each of the two factors, we consider three levels: low, medium, and high. The low and high volume demand levels are 75% and 125% of the medium level; while the low and high holding cost levels are 50% and 200% of the medium level. Hence, a total of nine experimental conditions are considered. An objective of considering the nine experimental conditions is to investigate which heuristics or groups of heuristics perform best under different scenarios. One hundred problems are created for each of the nine experimental conditions; hence, a total of 900 problems are solved by each of the 18 heuristics. We run our simulation on a Pentium-based microcomputer.

Four performance criteria are considered in this study. They are: (1) total production cost, (2) processing (including setup) cost, (3) holding cost and (4) penalty cost. Penalty cost occurs whenever the system fails to schedule all the necessary operations to meet the demand on time. In this case, a penalty is imposed as the firm may have to subcontract the products outside or employ other means of production to produce them, which can increase the cost considerably. Our study assumes a per unit processing cost twice as expensive as it would be produced in-house using the most inefficient or expensive machine. Finally, we also obtain optimal solutions of forty small size test problems for comparison analysis.

SIMULATION RESULTS

The presentation of the flowshop simulation results will be divided into three parts. The first part focuses on the overall results. Part 2 discusses the demand specific results. Finally, the third part presents the holding cost specific results.

Overall Results

The overall results according to the four performance criteria are shown in Table 1. For the total cost criterion, the Table shows that fmin(Z/Q) is the best; it is followed by fmax(Z/Q) with efficiency of 100.3%, and fmin(Z) with efficiency of 103.1%. The *f* heuristics in general outperform the *b* heuristics. The best *b* heuristic has an efficiency of 105.5%. Moreover, there is a larger range in relative performance for *b* heuristics than that of *f* heuristics. For example, *f* heuristics range from 100.0% to 118.7%, while *b* heuristics range from 105.5% to 142.3%.

Table 1: Overall Results

Heuristic	Total Cost	Efficiency	Holding C.	Efficiency	Process C.	Efficiency	Penalty C.	Efficiency
fmin(Z)	11532	103.1	492	270.1	9020	123.3	2020	187.8
fmin(Z-LB)	11566	103.4	503	276.5	9006	123.1	2057	191.2
fmin(Z/Q)	11190	100.0	428	235.2	9215	125.9	1547	143.7
fmax(Z)	11594	103.6	503	276.4	9050	123.7	2041	189.7
fmax(Z-LB)	11572	103.4	496	272.7	9050	123.7	2026	188.3
fmax(Z/Q)	11225	100.3	447	245.5	9157	125.1	1622	150.7
fmin(SUPT)	12178	108.8	760	417.4	8415	115.0	3003	279.1
fmin(STPT)	12256	109.5	658	361.7	9058	123.8	2540	236.1
f(LFL)	13280	118.7	746	409.8	9362	127.9	3171	294.7
bmin(Z)	11922	106.5	222	122.1	10481	143.2	1219	113.2
bmin(Z-LB)	11807	105.5	234	128.7	10398	142.1	1174	109.1
bmin(Z/Q)	12055	107.7	271	149.0	10395	142.1	1389	129.1
bmax(Z)	12553	112.2	235	129.2	11066	151.2	1251	116.3
bmax(Z-LB)	12797	114.4	235	129.1	10996	150.3	1566	145.6
bmax(Z/Q)	12497	111.7	334	183.3	10468	143.0	1695	157.5
bmin(SUPT)	12016	107.4	286	157.0	10270	140.3	1460	135.7
bmin(STPT)	12589	112.5	182	100.0	11330	154.8	1076	100.0
b(LFL)	15922	142.3	1295	711.6	7318	100.0	7309	679.2

Of the six *f* heuristics which outperform the best *b* heuristic, i.e., bmin(Z-LB), the Z/Q criterion (fmin(Z/Q) and fmax(Z/Q)) has the best performance. It is followed by Z (fmin(Z) and fmax(Z)) and Z-LB (fmin(Z-LB) and fmax(Z-LB)) criteria. On the other hand, the bmin heuristics with Z, Z/Q, and Z-LB criteria significantly outperform the bmax heuristics with the same criteria.

For the holding cost criterion, Table 1 shows that bmin(STPT) and b(LFL) have the best and worst performance, respectively. For the processing cost criterion, the opposite holds. Hence, the b(LFL) and bmin(STPT) have the best and worst performance, respectively. Since the b(LFL) has the highest holding cost, this hinders its ability to process more jobs on time; therefore, it ends up with a low processing cost. The behavior of bmin(STPT) can be explained in a similar fashion. For the penalty cost criterion, as in the holding cost criterion, bmin(STPT) and b(LFL) have the best and worst performance, respectively. The explanation follows that of the processing cost criterion results.

Demand Specific Results

For the total cost criterion, Table 2 shows that the fmax(Z/Q) performs the best for low and medium demand levels, while the fmin(Z/Q) has the best performance for high demand level. The total cost of fmin(Z/Q) is 1.1% higher than that of fmax(Z/Q) at the low level. They are virtually the same at the medium level, and the total cost of fmax(Z/Q) is 1.4% higher than that of fmin(Z/Q) at the high level. Hence, the Table indicates that as demand increases, fmin(Z/Q) replaces fmax(Z/Q) as the best heuristic.

Table 2: Demand Results – Total Cost Criterion

Heuristic	Low (75%) Efficiency	Med. (100%) Efficiency	High (125%) Efficiency
fmin(Z)	104.7	102.7	103.1
fmin(Z-LB)	103.8	103.7	103.5
fmin(Z/Q)	101.1	100.0	100.0
fmax(Z)	103.7	102.7	105.0
fmax(Z-LB)	102.3	103.0	105.1
fmax(Z/Q)	100.0	100.0	101.4
fmin(SUPT)	110.8	109.4	108.0
fmin(STPT)	110.6	109.9	109.4
f(LFL)	126.7	119.5	114.2
bmin(Z)	114.6	102.5	105.8
bmin(Z-LB)	114.3	101.0	104.7
bmin(Z/Q)	114.7	103.9	107.4

Table 2: Demand Results – Total Cost Criterion			
Heuristic	Low (75%) Efficiency	Med. (100%) Efficiency	High (125%) Efficiency
bmax(Z)	117.9	110.0	111.4
bmax(Z-LB)	120.3	113.0	112.7
bmax(Z/Q)	117.2	108.8	111.5
bmin(SUPT)	114.2	103.9	106.9
bmin(STPT)	119.1	110.7	110.8
b(LFL)	146.9	141.8	141.0

The *b* heuristics' relative performance improves drastically as the demand increases from the low to medium levels. Indeed, when the demand level is medium, the bmin(Z-LB) is the third best heuristic and its cost is just 1% higher than that of the best heuristic. However, as the demand increases from the medium to high levels, the *b* heuristics perform slightly worse. Nonetheless, the *b* heuristics still perform a lot better at high demand level than at low demand level.

For the holding cost criterion, Table 3 shows that bmin(STPT) has the best performance at all levels, while the b(LFL) has the worst performance. It is interesting to note that the holding cost of the *b* heuristics (except for b(LFL)) are significantly lower than that of the *f* heuristics. This is particularly true at low demand level. This can be explained by the scheduling flexibility of the *f* heuristics. When demand is low, the scheduling flexibility effect is particularly prominent; hence, the *f* heuristics trade the high holding costs for small processing costs. As demand increases, the scheduling flexibility effect lessens. Therefore, the performance gap between the *f* and *b* heuristics reduces drastically.

Table 3: Demand Results – Holding Cost Criterion			
Heuristic	Low (75%) Efficiency	Med. (100%) Efficiency	High (125%) Efficiency
fmin(Z)	17196	465.8	138.8
fmin(Z-LB)	17122	494.2	140.5
fmin(Z/Q)	14875	431.3	115.4
fmax(Z)	17288	473.4	144.3
fmax(Z-LB)	16316	457.1	148.5
fmax(Z/Q)	15273	430.4	126.3
fmin(SUPT)	26948	728.9	210.5
fmin(STPT)	24759	627.3	176.4
f(LFL)	24272	740.6	211.9

bmin(Z)	479	170.2	108.8
bmin(Z-LB)	491	183.9	113.7
bmin(Z/Q)	623	216.9	130.5
bmax(Z)	194	147.6	124.3
bmax(Z-LB)	1413	152.2	116.9
bmax(Z/Q)	312	278.6	160.1
bmin(SUPT)	563	275.0	127.1
bmin(STPT)	100	100.0	100.0
b(LFL)	45694	1339.9	337.6

Table 4: Demand Results – Processing Cost Criterion

Heuristic	Low (75%) Efficiency	Med. (100%) Efficiency	High (125%) Efficiency
fmin(Z)	115.2	121.8	130.8
fmin(Z-LB)	114.2	121.8	131.0
fmin(Z/Q)	116.8	123.7	134.9
fmax(Z)	113.9	122.7	132.0
fmax(Z-LB)	116.1	122.8	130.2
fmax(Z/Q)	115.8	124.0	133.3
fmin(SUPT)	108.0	113.8	121.5
fmin(STPT)	113.4	123.1	132.4
f(LFL)	124.1	124.2	134.3
bmin(Z)	151.5	137.9	141.9
bmin(Z-LB)	151.1	136.4	140.5
bmin(Z/Q)	151.6	137.6	138.9
bmax(Z)	155.9	150.2	148.6
bmax(Z-LB)	152.8	148.7	149.8
bmax(Z/Q)	155.0	139.7	137.0
bmin(SUPT)	151.0	133.8	138.3
bmin(STPT)	157.6	152.6	154.8
b(LFL)	100.0	100.0	100.0

For the processing cost criterion, Table 4 shows that b(LFL) performs the best at all three levels. Unfortunately, the small processing cost is at the expense of high penalty and holding costs.

With the exception of b(LFL), all nine *f* heuristics perform better than the *b* heuristics. However, the relative performance of the *f* heuristics deteriorate as the demand level increases.

For the penalty cost criterion, Table 5 shows that, with the exception of b(LFL), the *b* heuristics perform better than the *f* heuristics, particularly when demand is low. However, the *b* heuristics only perform slightly better than the *f* heuristics at high demand level.

Table 5: Demand Results – Penalty Cost Criterion

Heuristic	Low (75%) Efficiency	Med. (100%) Efficiency	High (125%) Efficiency
fmin(Z)	18157	246.7	128.1
fmin(Z-LB)	18123	258.9	129.1
fmin(Z/Q)	12427	190.4	101.1
fmax(Z)	18142	237.0	133.5
fmax(Z-LB)	14199	241.5	139.6
fmax(Z/Q)	11716	187.6	112.6
fmin(SUPT)	30726	395.9	173.2
fmin(STPT)	25593	322.0	151.2
f(LFL)	36973	441.3	165.6
bmin(Z)	0	117.3	112.1
bmin(Z-LB)	0	108.0	109.5
bmin(Z/Q)	100	134.9	127.1
bmax(Z)	0	108.2	118.6
bmax(Z-LB)	6311	169.4	123.8
bmax(Z/Q)	0	179.6	151.1
bmin(SUPT)	0	166.6	126.8
bmin(STPT)	0	100.0	100.0
b(LFL)	82631	954.7	405.7

* These heuristics yield a penalty cost of zero, so they are not used in the efficiency calculation.

Holding Cost Specific Results

For the total costs criterion, Table 6 shows that the fmin(Z/Q) performs the best at low and medium holding cost levels; while the fmax(Z/Q) performs the best at high holding cost level. Moreover, the increase in holding cost favors the *f* heuristics with Z, Z-LB, and Z/Q criteria.

This phenomenon can be explained as follows. Let's divide the 18 heuristics into three groups. Group A includes the six *f* heuristics with Z, Z-LB, and Z/Q criteria; group B includes the six *b* heuristics with Z, Z-LB, and Z/Q criteria; and group C includes the remaining six heuristics. As the holding cost level increases, the heuristics in group A respond by cutting inventory, so their holding costs are less than doubled from the low level to medium level, and from the medium level to high level. By carrying less inventory, they are able to process more jobs on time, so their processing costs increase significantly; hence, their penalty costs decrease significantly. Overall, their total costs, in fact, slightly decrease (about 1%) when the holding cost rate is doubled. As the decrease in penalty cost is more than offset by the increase in holding cost and processing cost. Nonetheless, the behavior of the total cost depends on how the penalty cost is computed.

Table 6: Holding Cost Results – Total Cost Criterion

Heuristic	Low (50%) Efficiency	Med. (100%) Efficiency	High (200%) Efficiency
fmin(Z)	103.9	103.1	103.2
fmin(Z-LB)	103.9	103.5	103.7
fmin(Z/Q)	100.0	100.0	101.0
fmax(Z)	104.6	104.5	102.8
fmax(Z-LB)	103.6	104.0	103.6
fmax(Z/Q)	100.7	101.2	100.0
fmin(SUPT)	105.1	108.0	114.5
fmin(STPT)	106.3	108.8	114.6
f(LFL)	115.0	117.8	124.3
bmin(Z)	105.9	106.5	108.3
bmin(Z-LB)	105.1	105.5	107.1
bmin(Z/Q)	106.6	107.5	110.2
bmax(Z)	110.5	112.5	114.7
bmax(Z-LB)	112.9	114.3	117.0
bmax(Z/Q)	110.2	111.6	114.3
bmin(SUPT)	106.1	107.1	110.0
bmin(STPT)	111.7	112.4	114.5
b(LFL)	135.9	140.8	151.7

The heuristics in group B responds to the increase in holding cost by cutting inventory slightly, so they are only able to marginally increase processing time. Hence, their penalty costs only decrease slightly. As the increase in holding and processing costs is more than the decrease in penalty costs, their total costs slightly increase (about 1%) when the holding cost rate is doubled.

The heuristics in group C do not respond to the increase in holding costs. Hence, their processing and penalty costs remain the same, while their holding costs double whenever the holding cost rate is doubled. Overall, their total costs increase slightly. Therefore, the relative performance of group A heuristics improves as the holding cost level increases.

For the holding cost criterion, Table 7 shows that the bmin(STPT) has the best performance at all levels. However, the heuristics classified in groups A and B improve their relative performance as the holding cost level increases.

Table 7: Holding Cost Results – Holding Cost Criterion

Heuristic	Low (50%) Efficiency	Med. (100%) Efficiency	High (200%) Efficiency
fmin(Z)	392.5	318.1	214.3
fmin(Z-LB)	403.8	321.9	220.9
fmin(Z/Q)	323.9	280.7	189.3
fmax(Z)	401.2	325.6	219.4
fmax(Z-LB)	374.0	326.8	219.2
fmax(Z/Q)	345.9	298.1	193.1
fmin(SUPT)	416.3	416.3	416.4
fmin(STPT)	360.8	360.8	360.9
f(LFL)	408.8	408.8	408.9
bmin(Z)	147.4	130.8	110.9
bmin(Z-LB)	153.9	140.3	116.0
bmin(Z/Q)	154.4	148.0	147.5
bmax(Z)	135.8	136.4	123.5
bmax(Z-LB)	131.4	131.0	127.0
bmax(Z/Q)	194.7	188.1	177.3
bmin(SUPT)	156.6	156.6	156.6
bmin(STPT)	100.0	100.0	100.0
b(LFL)	709.8	709.8	710.0

For the processing cost criterion, Table 8 shows that the b(LFL) performs the best at all three levels. Furthermore, as the holding cost level increases, the relative performance of group A heuristics deteriorates considerably; while the relative performance of group B heuristics deteriorates slightly.

For the penalty cost criterion, Table 9 shows the bmin(STPT) has the best performance at the low and medium levels, while the fmax(Z/Q) becomes the best heuristic at the high level. This is because the penalty costs of fmax(Z/Q) and group A heuristics decrease drastically as holding cost level increases, but the min(STPT)'s penalty cost remains the same at all three levels.

Table 8: Holding Cost Results – Processing Cost Criterion

Heuristic	Low (50%) Efficiency	Med. (100%) Efficiency	High (200%) Efficiency
fmin(Z)	117.1	122.5	130.3
fmin(Z-LB)	116.4	122.6	130.2
fmin(Z/Q)	121.2	124.8	131.7
fmax(Z)	117.7	123.1	130.2
fmax(Z-LB)	119.5	122.5	128.9
fmax(Z/Q)	120.2	124.0	131.2
fmin(SUPT)	115.0	115.0	115.0
fmin(STPT)	123.8	123.8	123.8
f(LFL)	127.9	127.9	127.9
bmin(Z)	141.5	143.0	145.2
bmin(Z-LB)	140.5	141.8	144.0
bmin(Z/Q)	141.8	142.0	142.4
bmax(Z)	150.4	151.0	152.3
bmax(Z-LB)	149.6	149.9	151.2
bmax(Z/Q)	142.4	142.8	144.0
bmin(SUPT)	140.3	140.3	140.3
bmin(STPT)	154.8	154.8	154.8
b(LFL)	100.0	100.0	100.0

CONCLUSIONS

We propose two general categories of scheduling procedures, namely forward and backward procedures to perform operations scheduling in MRP. Moreover, we develop various heuristic scheduling rules for use in the two general scheduling approaches. The proposed approaches are important because they help remove two major problems inherent in MRP: (1) setting planned lead time and (2) lot sizing determination and are able to yield detailed production schedules to minimize total production cost.

A simulation experiment is conducted to test the performance of 18 proposed heuristics under the flowshop environment. Based on our computational results, the fmin(Z/Q) heuristic possesses the best overall performance, it is followed by fmax(Z/Q) and fmin(Z). It is interesting to note that Ho and Chang (2005) found that fmax(Z) yielded the best overall performance under the jobshop environement, the next two best heuristics being fmax(Z/Q) and fmin(Z/Q).

Table 9: Holding Cost Results – Penalty Cost Criterion

Heuristic	Low (50%) Efficiency	Med. (100%) Efficiency	High (200%) Efficiency
fmin(Z)	254.0	192.1	139.3
fmin(Z-LB)	257.7	194.9	143.9
fmin(Z/Q)	190.4	149.1	109.0
fmax(Z)	256.3	200.9	133.1
fmax(Z-LB)	235.9	199.4	153.9
fmax(Z/Q)	203.5	164.6	100.0
fmin(SUPT)	279.1	279.1	331.8
fmin(STPT)	236.1	236.1	280.7
f(LFL)	294.7	294.7	350.4
bmin(Z)	126.1	115.1	117.1
bmin(Z-LB)	124.2	110.6	110.1
bmin(Z/Q)	131.3	129.8	149.9
bmax(Z)	114.8	121.7	133.6
bmax(Z-LB)	144.6	149.2	170.0
bmax(Z/Q)	162.4	161.2	177.0
bmin(SUPT)	135.7	135.7	161.4
bmin(STPT)	100.0	100.0	118.9
b(LFL)	679.2	679.2	807.6

REFERENCES

Baker, K.R. (1984). Sequencing rules and due-date assignments in a job shop. *Management Science*, *30*, 1093-1104.

Belt, B. (1987). MRP and Kanban - A possible synergy? *Production and Inventory Management*, *28*, 71-80.

Betz, H.J. (1996). Common sense manufacturing: A method of production control. *Production and Inventory Management*, *37*, 77-81.

Benton, W.C. & H. Shin (1998). Manufacturing planning and control: The evolution of MRP and JIT integration. *European Journal of Operational Research, 110*, 411-440.

Blackburn, J.H. (1985). Improve MRP and JIT compatibility by combining routings and bills of material. *Proceedings of the American Production and Control Society*, 444-447.

Bose, G.J. & A. Rao (1988). Implementing JIT with MRP II creates hybrid manufacturing environment. *Industrial Engineering*, *20*, 49-53.

Chaudhury, A. & A.B. Whinston (1990). Towards an adaptive Kanban system. *International Journal of Production Research*, *28*, 437-458.

Deleersnyder, J.L., T.J. Hodgson, R.E. King, P.J. O'Grady & A. Savva (1992). Integrating Kanban type pull systems and MRP type push systems: Insights from a Markovian model. *IIE Transactions*, *24*, 43-56.

Ding, F.Y. & M.N. Yuen (1991). A modified MRP for a production system with the coexistence of MRP and Kanbans. *Journal of Operations Management*, *10*, 267-277.

Discenza, R. & F.R. MacFadden (1988). The integration of MRP II and JIT through software unification. *Production and Inventory Management, 29*, 49-53.

Flapper, S.D., G.J. Miltenburg & J. Wijngaard (1991). Embedding JIT into MRP. *International Journal of Production Research*, *29*, 329-341.

Goyal, S.K. & A. Gunasekaran (1990). Multi-stage production-inventory systems. *European Journal of Operational Research*, *46*, 1-20.

Ho, J.C. & Y.L. Chang (2001). An integrated MRP and JIT framework. *Computers & Industrial Engineering*, *41*, 173-185.

Ho, J.C. & Y.L. Chang (2005). Heuristics for scheduling operations in MRP: Jobshop case. *International Journal of Industrial Engineering*, *12*, 322-334.

Ho, J.C. & Y.L. Chang (2006). Incorporating operations scheduling in MRP: A mathematical programming approach. *Working Paper.*

Huge, E.C. (1979). Managing manufacturing lead times. *Harvard Business Review*, *57*, 116-123.

Huq, Z. & F. Huq (1994). Embedding JIT in MRP: The case of job shops. *Journal of Manufacturing Systems*, *13*, 153-164.

Kanet, J.J. (1982). Toward understanding lead times in MRP systems. *Production and Inventory Management*, *23*, 1-14.

Karmarker, U.S. (1989). Gettting control of just-in-time. *Harvard Business Review*, *67*, 122-131.

Karmarker, U.S. (1993). Manufacturing lead times, order release and capacity loading. In S. Graves, A. Rinnooy Kan, & P. Zipkin (Eds.), *Logistics of Production and Inventory* (Vol. 4). Amsterdam: Elsevier.

Orlicky, J. (1975). *Material requirements planning*. New York, NY: McGraw-Hill.

Pinedo, M. (2002). *Scheduling theory, algorithms, and systems*. Upper Saddle River, NJ: Prentice-Hall.

Plossl, G.W. & W.E. Welch (1979). *The role of top management in the control of inventory*. Reston, VA: Reston Publishing.

Silver, E.A., D.F. Pyke & R. Peterson (1998). *Inventory management and production planning and scheduling*. New York, NY: John Wiley & Sons.

St. John, R. (1985). The cost of inflated planned lead times in MRP systems. *Journal of Operations Management*, *5*, 119-128.

Vollmann, T.E., W.L. Barry, D.C. Whybark & F.R. Jacobs (2005). *Manufacturing planning and control for supply chain management*. New York, NY: McGraw-Hill.