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Using a genetic algorithm-based system for the design of EDI controls: EDIGA

Sangjae Lee*

Techno-Management Research Institute, Korea Advanced Institute of Science and Technology, 207-43 Cheongryangri-Dong Dongdaemun-Gu, Seoul 130-012, South Korea

Abstract

The extent of major advantages and benefits derived from Electronic Data Interchange (EDI) depends upon the usage of EDI controls. EDI cannot be adopted and implemented if users are not sure about the advantages of the system. Auditors should concentrate their limited IS resources to design and effectively implement the controls that lead to highest EDI implementation and performance. This study tries to determine the *Relative Importance* that different modes of controls have in determining EDI implementation and performance, which will aid the design of EDI controls by auditors. This study proposes EDIGA (EDI-controls design using Genetic Algorithms), a hybrid optimization model using genetic algorithms for the design of EDI controls, that combines the search efficiency of GA with the simplicity of statistical technique, regression analysis to identify the *Relative Importance* of each mode of EDI controls. The estimated parameters in EDIGA are analyzed to obtain insights on the effect of EDI controls on EDI implementation and performance. The empirical investigation consists of testing EDIGA, which employs a pattern directed search mechanism to produce the best fitting *power* model versus linear regression analysis as a method to evaluate the effectiveness of EDIGA. It turns out that the predictive accuracy of EDIGA outperforms that of linear regression analysis. The results of study will help companies to implement EDI controls successfully.

Keywords: Electronic data interchange; Controls; Genetic algorithms; Electronic data interchange implementation; Electronic data interchange performance

1. Introduction

Electronic Data Interchange (EDI) is an application of information technology that allows business partners exchange transaction documentation in structured, machine-processable form over telecommunication networks. The concept of internet-based EDI has been introduced due to the arrival of the commercial use of the Internet, driven by its World Wide Web (WWW) subset. The Internet makes it feasible to interconnect a vast range of business applications, reduces setup costs, and provides readily available ubiquitous access with few geographical constraints (Segev, Porra & Roldan, 1997; Senn, 1998). Many value added networks (VANs) have begun to offer internet-based EDI service, as an increasing number of firms consider moving their EDI transactions to the Internet (Kalakota & Whinston, 1996).

It would be entirely wrong to consider electronic commerce as a purely technological issue (Zwass, 1996). One such problem is the security and integrity of electronic commerce. The high value and degree of automation associated with EDI systems makes the potential loss resulting from inappropriate planning and maintenance of controls even higher. Major financial losses can result from fraud in poorly controlled Electronic Funds Transfer (EFT) (Boef, 1999). This is especially true when EDI is implemented due to external pressure from industry and trading partners without regard to security and controls (Mehta, 1998).

EDI controls play an important role in achieving the objective of lowering the risks of EDI. It is highly likely that users will consider the communication of EDI systems useless if the system is insecure and inaccurate, especially in financial applications. If EDI is used in payment transactions, minor errors in the communication of transactions can lead to severe degradation of system performance. The EDI system cannot be further integrated and utilized if it produces erroneous information to inner applications, which leads to degradation of system performance. Management should demand the assurance that adequate controls are in place in the terms of compliance before they implement the EDI system.

It will be inefficient, however, to implement expensive controls in the subsystems if the extent of EDI implementation is not high; the sensitivity and vulnerability of the system may not be high. As high expertise and funds are

* Tel.: +82-2-958-3673; fax: +82-2-958-3604.
E-mail address: sangjae@kgsm.kaist.ac.kr (S. Lee).

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required for the implementation of controls (Lawrence, 1988), the guidance of control designs needs to be given such that the implementation of controls is cost-effective. Although it is critical to adjust the appropriate level of controls in order to satisfy the objective of EDI systems, the determination of the level of IS controls receives only limited attention in academic research as well as in business. There has not been a single investigation into the effective selection of controls in view of the extent of EDI implementation and performance. Furthermore, although there is a large body of applications of genetic algorithms (GAs) in the field of engineering and computer science, relatively little work has been done concerning business-related applications. GAs are a promising approach to improve their judgements on the implementation of EDI controls. GAs are search techniques for global optimization in a complex search space. They employ the concepts of natural selection and genetics.

This study presents EDI-controls design using Genetic Algorithms (EDIGA), a hybrid genetic optimizer that combines the search efficiency of GA with the simplicity of a statistical technique, to identify the design configuration that maximize the EDI implementation and performance. EDIGA employs a pattern directed search mechanism to produce the best fitting *power* model. The hybrid GA model is empirically tested using data collected from Korean firms that have adopted EDI. The estimated parameters in EDIGA are analyzed to obtain insights on the effect of EDI controls on EDI implementation and performance. The empirical investigation consists of testing EDIGA versus multivariate linear regression analysis as a method to evaluate the effectiveness of EDIGA. Reasoning process of control design is described using an illustrative example. The discussion of results and implications are also included in the study.

2. Genetic algorithms

GAs maintain and manipulate a population of solutions in their search for better solutions. GAs are based on a randomized search and adopt a random choice as a means to guide a highly explosive search through a coding of a parameter space. GAs have been used to solve linear and nonlinear problems by searching all regions of the state space and exponentially exploring promising areas through mutation, crossover, and selection operations applied to individuals in population (Goldberg, 1978). Although GAs do not guarantee the best possible solution, GAs are applied as heuristic procedures, which like evolution in living organisms, to improve results in each generation as it adapts to environmental conditions.

GAs perform optimization process in four stages: initialization, selection, crossover, and mutation (Davis, 1991). In the initialization stage, the search space of all possible solutions is mapped onto a set of finite strings. Each string (called chromosomes) has a corresponding point in the search space. The algorithm starts with the initial solutions that are selected from a set of configuration in the search space called *population* using randomly generated solutions or with special algorithms. Each of initial solutions (called initial population) is evaluated using a user-defined fitness function. A *fitness* function exists to numerically encode the performance of the chromosome.

A set of individuals that have high scores in fitness function is selected to reproduce itself. Such a selective process results in the best-performing chromosomes in the population to occupy an increasingly larger proportion of the population over time. From the selected set of individuals, some progeny is generated by applying different genetic operators (i.e. crossover, mutation).

Crossover operates by swapping corresponding segments of a string representation of a couple of chromosomes (called “parents”) to produce two chromosomes (called “children”). The simplest one is one-point crossover: a cutting site is chosen at random and the children are obtained by each taking the first part of from one parent and the second from the other. Mutation operates on a single chromosome: one element is chosen at random from the chain of symbols and the bit string representation is changed with another one.

Two parent individuals are selected from the present population and evolutionary production operators (i.e. crossover, mutation) are applied to produce a set of new solutions. The new individuals’ fitness is completed and they are included in the population. Individuals “stay alive” if they have high fitness.

GAs have been used in a number of applications in mathematics, medicine, engineering and political science (Dorigo, 1989). Recently, they applied to, for example, decision support system for product design (Balakrishnan & Jacob, 1995), stock/equity portfolio management models (Leinweber & Arnott, 1995), competitive structure analysis (Klemz, 1999), scheduling (Li, 1998), and competitive strategies (Midgley, Marks & Cooper, 1997). GAs are especially useful for multi-parameter function optimization problems with an objective function subject to numerous hard and soft constraints in search of high dimension, nonlinear and discontinuous search spaces (Goldberg, 1989). These concepts were developed by Holland (1975). GA is used in this study for multi-parameter optimization problem to optimally estimate the effect of EDI controls on EDI implementation and performance. Many examples exist in which genetic programs are tested against from known mathematical functions and are able to discover mathematical functions that fit the data (Koza, 1992). Since regression is one of the classical techniques in statistics, this can be the first place to apply GAs in this manner. The most straightforward method doing this would be to use the residual sum of squares (RSS) as a fitness function and to select optimal parameter (i.e. coefficients

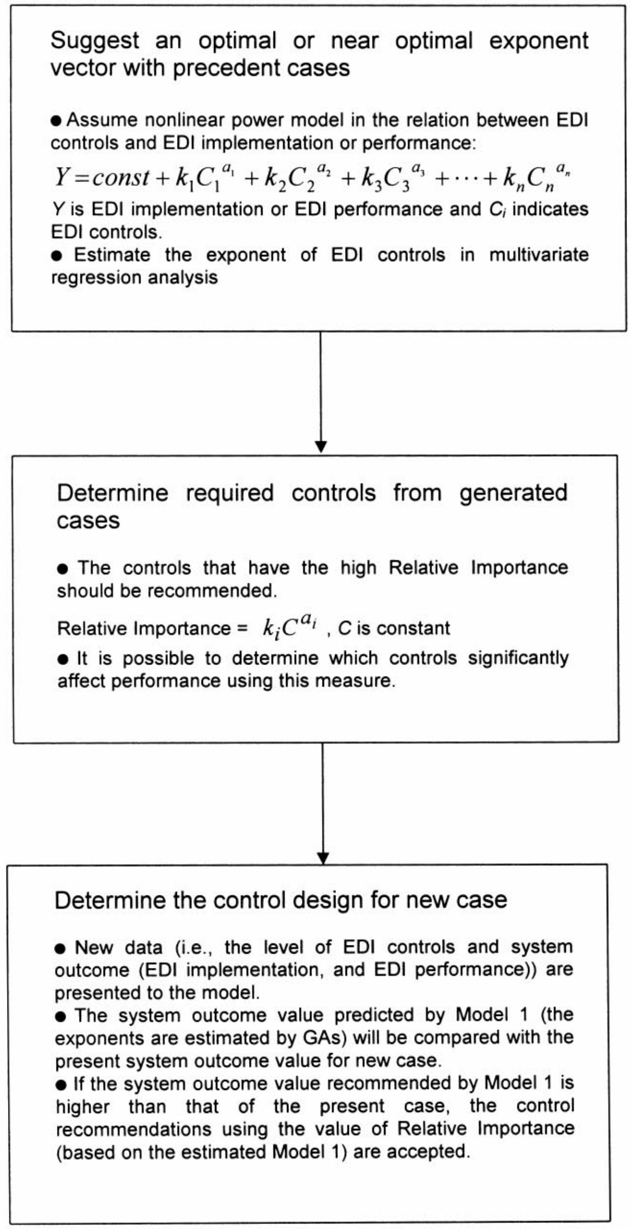

Fig. 1. Overview of the EDIGA Model.

and exponents of independent variables) estimates of regression equation.

3. EDI controls and EDI implementation

The rapid decrease in the cost of communication technology along with the widespread use of microcomputers has resulted in the extensive deployment of computers for use by employees. The high sophistication of IS, however, requires high usage level of IS controls. Each incremental level of integration requires a higher level of security and integrity. A domino effect from the mishaps of one application or external networks makes the vulnerability of system increase from the integration with internal systems.

Some internal applications planned for computerization might have to be done manually if sufficient security is not provided in computer use (Parker, 1981, 1994). "Control assurance" in EDI must be provided to stakeholders such as internal users, trading partners, and industrial associations, in terms of contractual obligations or agreements before the decisions regarding further implementation of the system can be made (Chan, Govindan, Picard & Leschiutta, 1993). An "adequate" level of controls, specified in trading partner agreements, should be established before connecting their system to trading partners' systems (Jamieson 1994; Mehta 1998). The cost of errors can be quite high when the system is automated to a large extent without human intervention. The management needs to ensure security of information using policies, organizational structures, practices, and procedures. The incorporation of more powerful control mechanisms into computers and networks, both hardware-based as well as software-based, is necessary while automating organizational functions. Before an organization decides to implement EDI, the controls for EDI need to be planned in order to give a belief that system is safe and accurate to users or increase the capability of implementation and adjustment.

The competitive advantage from EDI can be derived only if the integrity and accuracy of data are controlled. The savings of administrative and operating cost can be wiped out by deliberate or erroneous loss of data during data communication. Customer service is improved with the avoidance of paper manipulation and data re-entry by recipient partner organization; this improvement thereby requires the usage of standardized procedures and data integrity controls of the communication process. Standardizing and formalizing the communication process and procedures improves the speed, accuracy, and completeness of partner communications (Stern & Kaufmann, 1985). Cost-effectiveness of controls can be ensured when the integration and utilization of system becomes greater, as there exists large volume of transactions to be processed at high speed.

4. A hybrid genetic optimizer

Hybridization of techniques can result in better systems if it has synergistic combination. GAs have been used successfully in combination with other techniques such as search algorithms (Chockalingam & Arunkumar, 1995; Glover, Kelly & Laguna, 1995; Holsapple, Jacob, Pakath & Zaveri, 1993), a fuzzy reasoning model (Park, Kandel & Langholz, 1994), *k*-nearest neighbors clustering algorithm (Kumar, Krovi & Rajagopalan, 1997), neural networks (Back, Laitinen & Sere, 1996; Coit & Smith, 1996; Hansen, 1998). For instance, the integration of GAs and neural networks is a rapidly expanding area. The examples of the use of GAs in neural network design include selection of relevant input variables, identifying the optimal hidden layers and connectivity, and determining the learning conditions (Harp & Samad, 1991; Wong & Tan, 1994).

EDIGA is a heuristic procedure that tends to improve results in each generation as it adjusts to environmental conditions. Fig. 1 illustrates the overall procedures to set up EDIGA model, which are explained below.

(1) Suggest an optimal or near optimal exponent vector with precedent cases. The hybrid GA implemented in this study suggests that GAs can be used to learn the weights or coefficients associated with the variables (i.e. EDI controls) in the training set. One of traditional techniques in prediction tasks is statistical analysis such as regression analysis, time series analysis, and discriminant analysis, Multivariate regression analysis has been extensively employed in prediction tasks when dependent variables are continuous. As appropriate EDI controls increase the potential for EDI implementation (Lee, Han & Kym, 1998) which is related to EDI performance (Premkumar, Ramamurthy & Nilakanta, 1994), it is hypothesized that EDI implementation and performance is a function of EDI controls. The relationship between EDI controls and EDI implementation or performance can be modeled in a lineal or nonlinear equation. In this study, a nonlinear regression equation is used in order to describe better the complex relationship between controls and EDI implementation or performance. A scatterplot is a good means for judging how well a straight line fits the data. When the data are plotted and they do not cluster around a straight line, various transformation can be applied such as taking logs of the independent variable, to try quadratic, cubic, logistic, exponential models. It is assumed that EDI controls are related to performance in the following power model:

$$\text{Model 1}: \; Y = \text{const} + k_1 C_1^{a_1} + k_2 C_2^{a_2} + k_3 C_3^{a_3} + \ldots + k_n C_n^{a_n}$$

Y is the EDI implementation or EDI performance and C_i indicates EDI controls. k_i is estimated through regression analysis. The method of least squares results in a line that minimizes the sum of squared vertical distances from the observed data points to the line. The exponent, a_i of EDI controls can be adjusted to account for the importance of the controls. EDI controls that are not useful in predicting dependent variables (EDI implementation and EDI performance) may have smaller value of exponents. This allows auditors to accurately determine important controls to explain much of the dependent variables. Optimization techniques are used to find the best set of parameters that minimizes error. The exponent, a_i is estimated using GA to minimize the RSS of the regression equation. GAs begin their work with a randomly constructed population of initial guesses to parameter. Potential solutions that are more fit, or lead to lower RSS, receive priority in subsequent generations. The population will converge eventually with the fittest solutions surviving.

Mathematically speaking, the objective of controls design problem is to minimize the RSS (i.e. fitness function) of Model 1 and find out the optimized solutions of exponents in order to discover the Relative Importance of each mode of controls:

$$\text{Min RSS} = \sum_{i=1}^{N} (Y_i - \hat{Y}_i)^2$$

$$0 \le a_1 \le 1$$

Evolver 3.1, a developing tool for GAs based systems was used as a GA tool to develop EDIGA. Evolver provides users with an easy way to find optimal solutions using GAs. Excel spreadsheet model is used to define case

	A	B	C	D	E	F	G	H
1								
2		Controls	Exponent					
3		C1	0.02					
4		C2	0.02		All Exponents < 1 and > 0 ?			
5		C3	0.12		TRUE			
6		C4	0.99					
7		C5	0.07					
8		C6	0.00					
9		C7	0.01					
10		C8	0.86					
11		C9	0.01					
12		C10	0.03					
13		C11	0.11					
14		C12	0.94					
15								
16								
17		Controls	Coefficent	SE		R Square	0.20	
18		C1	-0.03	0.25		SE of Y	1.35	
19		C2	-3.38	4.34		F	1.82	
20		C3	11.78	14.30		d.f.	87.00	
21		C4	244.89	105.98		Regrssion SS	39.58	
22		C5	0.04	0.22		Residual SS	157.76	
23		C6	10.29	6.34				
24		C7	-2.77	1.45				
25		C8	-2.52	8.93				
26		C9	0.16	0.19				
27		C10	-5.34	4.54				
28		C11	-18.98	24.26				
29		C12	83.30	46.84				
30								

Fig. 2. Spreadsheet included in the formulation of EDIGA. C1: internal formal application controls, C2: internal formal communication controls, C3: external formal VAN controls, C4: external formal partner controls, C5: internal informal controls by IS members, C6: internal informal controls by users, C7: external informal controls for VAN, C8: external informal controls for partners, C9: internal automated application controls, C10: internal automated communication controls, C11: external automated controls by VAN, C12: external automated controls by trading partners, SS: Sum of squares, SE: Standard error.

structures and relevant features—constraints and objective functions—of cases, and to automatically build an interactive questionnaire to collect and edit the cases. It results in a customized model which offers a sophisticated means of analyzing cases. Auditors elect to enter data about EDI systems and controls into the spreadsheet model and analyze using Evolver. Excel provides all of the formula, functions, graphs, and macro capabilities that most users need to build realistic models of their interests. Evolver is used to find the right mix, order, or grouping of variables that produces the lowest risks and the highest profits. After Excel spreadsheet is used to set up a model of problems and Evolver is called up to solve it.

Fig. 2 presents the spreadsheet that portrays the EDIGA. Evolver finds solutions by relying on the relationships that already exist in the spreadsheet. The variables to be adjusted, i.e. the exponents of controls are in cells in C3:C14. The exponent of each independent variable is constrained not to be larger than 1 and smaller than 0. Hence, the spreadsheet has the constraint cell that all the exponents should be smaller than one and larger than zero. The constraint cell is positioned in E5 and must always be "TRUE" for all valid solutions. The objective function is to minimize the RSS and the cell is set to G22. The coefficients, RSS, and other estimates of regression analysis that are defined using Excel function of regression analysis are automatically computed based on the exponent values provided from Evolver. The objective function provides feedback, indicating how good or bad each guess that Evolver makes is, and enabling Evolver to breed incrementally better guesses.

(2) Determine required controls from generated cases. The controls that have the high Relative Importance should be recommended. The Relative Importance to dependent variables (EDI implementation or EDI performance) can be assigned after the parameters in Model 1 are estimated. The larger is the absolute value of the correlation coefficient, the stronger is the association between exponent a_i of C_i and Y. One way to make controls comparable is to calculate the following formula:

$$\text{Relative Importance} = k_i C^{a_i}, \qquad C \text{ is constant}$$

The above value is the Relative Importance of control i. The constant, C is arbitrarily given such that C_i and $C_j (i \neq j)$ can be compared. It may be set to any value, but the median value of controls (i.e. 4) is used for the constant. It is possible to determine which controls significantly affect performance using this measure. Auditors or organization managers should place more emphasis on the controls that produce high performance—those with high Relative Importance (e.g. 1).

(3) Determine the control design for new case. This step is a production phase. New companies which have adopted (or will adopt) EDI are initially contacted and their EDI practitioners or managers are interviewed to obtain data about EDI controls, implementation, and performance.

Table 1
Measurements of research variables (NA: because the variable is composed of a single item, no reliability and validity analysis is conducted)

Class	Variables	Measure description	Sources
Internal formal controls	Internal formal application controls (alpha = 0.710)	● System change control by authorization (IFAC1)	Adapted from Chan et al. (1993), ISACA (1990), Jamieson (1994) and Marcella and Chan (1993)
		● Integrity check of the message before processing in the application (IFAC2)	
		● Transaction log for the possible errors and collapse (IFAC3)	
		● Appropriate system login procedures using password (IFAC4)	
	Internal formal communication controls (alpha = 0.791)	● Integrity check after generating EDI messages (IFCC1)	
		● Authentication of trading partners after receiving EDI messages (IFCC1)	
External formal controls	External formal VAN controls (alpha = 0.861)	● Back up and recovery plan by VAN (EFVC1)	
		● Retransmission after correcting erratic messages by VAN (EFVC2)	
		● Dispute reconciliation procedures by VAN (EFVC3)	
		● Access control on network by VAN (EFVC4)	
		● Mailbox access control by VAN (EFVC5)	
	External formal partner controls (alpha = 0.783)	● Back up and recovery plan by trading partners (EFPC1)	
		● Retransmission after correcting erratic messages by trading partners (EFPC2)	
		● Dispute reconciliation procedures by trading partners (EFPC3)	
		● Access control on network by trading partners (EFPC4)	
Internal informal controls	Internal informal controls by IS members (alpha = 0.849)	● Recognition of possible propagation of errors from one system to another by IS members (IICIS1)	Adapted from Jaworski et al. (1993)
		● Recognition of the importance of their responsibility IS members (IICIS2)	
		● Ability to judge peer's errors in their tasks by experience IS members (IICIS3)	
		● Ability to cope with the errors effectively by experience IS members (IICIS4)	
		● Interaction with seniors or peers to cope with problems in their tasks IS members (IICIS5)	
	Internal informal controls by users (alpha = 0.898)	● Recognition of possible propagation of errors from one system to another by users (IICUSE1)	
		● Recognition of the importance of their responsibility by users (IICUSE2)	
		● Ability to judge peer's errors in their tasks by experience by users (IICUSE3)	
		● Ability to cope with the errors effectively by experience by users (IICUSE4)	
		● Interaction with seniors or peers to cope with problems in their tasks by users (IICUSE5)	
External informal controls	External informal controls for VAN (alpha = 0.814)	● Recognition of the effect of errors in VAN (EICV1)	
		● Recognition of importance of interorganizational cooperation with VAN (EICV2)	
		● Processing nonroutine problems between VAN by experience (EICV3)	
		● Recognition of importance of items in the agreement between VAN (EICV4)	

Table 1 (*continued*)

Class	Variables	Measure description	Sources
		● Interaction between VAN to process message errors (EICV5)	
	External informal controls for partners (alpha = 0.798)	● Recognition of the effect of errors in trading partners (EICP1)	
		● Recognition of importance of interorganizational cooperation with trading partners (EICP2)	
		● Processing nonroutine problems between trading partners by experience (EICP3)	
		● Recognition of importance of items in the agreement between trading partners (EICP4)	
		● Interaction between trading partners to process message errors (EICP5)	
Internal automated controls	Internal automated application controls (NA)	● Programmed integrity check before processing in application systems (IAAC1)	Adapted from Chan et al. (1993), ISACA (1990), Jamieson (1994) and Marcella and Chan (1993)
		● Applying access control software on critical application and files (IAAC2)	
	Internal automated communication controls (alpha = 0.718)	● Automated data integrity check before transmission of EDI messages (IACC1)	
		● Automated authentication of trading partners using message code (IACC2)	
External automated controls	External automated controls by VAN (alpha = 0.777)	● Automated transaction log for EDI messages by VAN (EACV1)	
		● error message tracing and error reporting by VAN (EACV2)	
		● Digital signatures(message authentication code) provided by VAN (EACV3)	
		● Provision of various protocol function by VAN (EACV4)	
		● Provision of various EDI document standard by VAN (EACV5)	
	External automated controls by trading partners (alpha = 0.667)	● Automated transaction log for EDI messages by trading partners (EACP1)	
		● Error message tracing and error reporting by trading partners (EACP2)	
		● Digital signatures(message authentication code) provided by trading partners (EACP3)	
Implementation	Integration (NA)	● Integration of EDI in five application systems	Adapted from Premkumar et al. (1994) and Whang (1991)
	Utilization (NA)	● Utilization of EDI in five application systems	
Performance	Improved relation (alpha = 0.891)	● Improvement of relationship by reduced response time (REL1)	Adapted from Arunachalam (1995), Banerjee and Golhar (1994) and Hansen and Hill (1989)
		● Improvement of relationship by reduced delay from errors (REL2)	
		● Improvement of trust by enhanced confidentiality of documents (REL3)	
		● Improvement of relationship by reduced omission or inaccuracy in transmission (REL4)	
		● Maintenance of trust by protected messages from disclosure to third parties (REL5)	
	Competitive advantage (alpha = 0.868)	● Increase in efficiency of interdepartmental transaction processing (ADV1)	
		● Increase in accuracy by reduced paper work (ADV2)	
		● Reduction of transaction processing costs (ADV3)	

New data (i.e. the level of EDI controls and system outcome (EDI implementation, and EDI performance)) are presented to the model. The system outcome value of implementation (i.e. integration and utilization) or performance predicted by Model 1 (the exponents are estimated by GAs) will be compared with the present system outcome value for new case. If the system outcome value recommended by Model 1 is higher than that for the present case, the control recommendations using the value of Relative Importance (based on the estimated Model 1) are accepted. If the system outcome value recommended by Model 1 is lower than that of the current case, the current usage level of EDI controls are retained and regarded as “good” to ensure successful EDI implementation or performance. This is based on the assumption that “better” EDI controls will lead to greater EDI implementation and performance.

The new data are given to the EDIGA’s interactive consultation system and the casebase is updated as new information (e.g. EDI controls, implementation, performance) about the current case is entered by EDI auditors. The data from the present case along with recommended controls are entered into the database so that auditors can make decisions on the basis of the newly updated casebase.

Because optimization results can differ according to various learning conditions, it is necessary to select the specific value of exponents of EDI controls that result in high performance. The controls having the highest value in performance across various learning results comprise the controls to be recommended.

5. Modes of EDI controls

EDI controls can be broadly defined as the activities to safeguard assets, maintain data integrity, accomplish organizational goals effectively, and consume resources efficiently (Weber, 1988). The objectives of EDI controls in this study are asset safeguarding, integrity, and confidentiality.

Three types of controls exist; formal, informal, and automated controls. Formal EDI controls are “written management-initiated” controls and are based on written procedures. Formal mechanisms include rules, regulations, and hierarchy of authority to ensure the security and integrity of EDI, and are used to direct the behavior and assess performance. For instance, formalized procedures of maintaining user password, change control procedures for access control software are formal controls (e.g. Mehta, 1998). Informal controls are based on the beliefs and values shared by members of an organization. Informal EDI controls are initiated by organization members using the members’ values, judgments, and communications. Informal controls have the following components; risk recognition, sense of responsibility, experience, and interaction among the members of the EDI staff based on former IS security and control studies. The examples of informal controls include experience, user recognition of responsibility and faithfulness to the procedures in order to increase the effectiveness of the control system (e.g. Frank, Shamir & Briggs, 1991; Harrington, 1996). Automated EDI controls indicate automated control procedures and methods. They include programmed integrity check and security and authentication software (Powell, 1994). Automated access control software, and embedded audit routines are also necessary as the access process becomes routine and repetitive (Zoladz, 1994). Automated access control software and integrated test facilities become important, as they can detect and correct invalid or unauthorized accesses more accurately than manual systems in repetitive and routine processes.

Three types of controls; formal, informal, and automated controls can be further classified into intern and external controls. Internal controls deal with internal components of EDI systems such as the application system interface, while external controls are involved with external EDI systems such as a VAN or a trading partner. Internal controls for EDI systems are established to monitor the internal application systems like a production system or a sales system linked to an external network. External controls like those of VANs and trading partners have special importance: to check invalid or unauthorized transactions that can be initiated by the staff in a third-party network, and to ensure integrity of messages that could be lost, altered, duplicated, or transposed while they are transmitted through the network. There are 12 potential control modes as shown in Table 1.

6. Measurement of variables

The measures for EDI controls were newly developed in this study from the extensive review of EDI control checklists suggested by Information System Audit and Control Association (ISACA) and they were refined based on other EDI literature such as Chan et al. (1993), Jamieson (1994) and Marcella and Chan (1993). EDI controls are measured on seven-point Likert-type scales (Table 1).

Successive interviews with EDI practitioners who are cognizant of managerial and technical aspects of EDI controls improved the first version of measures of EDI controls; the wording, interpretation of the measures, and the possession of knowledge necessary to answer the questionnaire were examined. Four IS professors made a final review. Respondents answer the extent to which they agree or disagree with each statement about controls such as: “integrity check of messages is strictly performed before the messages are processed in the application” (item FC2). The final sample data was collected using structured interviews with EDI practitioner. Only qualitative measures are used, as it is very difficult to determine the usage level of EDI controls in quantitative manner (e.g. labor cost of security staffs, investment cost of security software).

EDI implementation has two dimensions, *integration*,

Table 2
Average RSS by Model 1 and Model 2 ($***p < 0.01$, $**p < 0.05$, $*p < 0.1$)

Dependent variables	Models				
	Model 1	Model 2	Difference	t value	p-value
Integration	21.46	22.63	−1.17	−2.379	0.049 ***
Utilization	1.17	1.03	0.13	1.608	0.146
Improved relationship	8.03	8.80	−0.77	−3.076	0.054 *
Competitive advantage	12.20	12.98	−0.77	−1.385	0.260

and *utilization.* The items for these measures are adapted from Premkumar et al. (1994) and Whang (1991). First, EDI should be integrated with IS applications in order to be effective (e.g. Iacovou, Bennasat & Dexter, 1995). The key to effective use of EDI is to integrate information collected through EDI with internal IS applications so that effectiveness and efficiency of the operation can be improved. Better customer service and improved inter-firm relationships are possible from system integration because customers' needs can be promptly met (Arunachalam, 1997; Drury & Farhoomand, 1996; Emmelhainz, 1986; Iacovou et al., 1995).

Integration is measured by the level of integration of five application systems which respondents believe to be very closely connected with EDI. Although they have many organizational tasks, the scope of applications that are related to EDI is mostly limited. Five tasks (e.g. trade, retail, payment system)—some companies have less than five tasks—are selected by respondents; these tasks are believed to be most closely connected with EDI and can represent the characteristics of EDI applications of EDI adopters at the organizational level. Integration is defined by the extent to which EDI data can be directly processed within applications without human intervention. This is measured using a seven point Likert-type scale. The measure of *utilization* indicates the proportion that a company used EDI in the five applications that can be processed through other means. It is the proportion of a firm's information exchange and processing that is handled through EDI. The utilization of EDI means the extent to which an organization handles its business transactions electronically to support higher-level aspects of organizational work and to facilitate the widespread transfer of technology to other application systems in the organization.

Mere measurement of EDI integration and utilization may not be sufficient indicators of success until EDI adopters perceive high benefits from the implementation of technology. Installed systems may fail to provide the intended benefits to firms. The measures for EDI performance are based on various EDI survey results (Arunachalam, 1995; Banerjee & Golhar, 1994; Hansen & Hill, 1989) and EDI management and controls (Chan et al., 1993; Emmelhainz, 1990; Jamieson, 1994; Marcella & Chan, 1993). The measures of perceived EDI performance can be sought from the objectives of EDI usage. The reinforcement of ties with a business partner, improved customer service, cost reduction and increased reliability of information are the most important benefits recognized by the majority of respondents.

Extensive precautions taken during the previous stages of development and pilot testing of the items established the content validity of measures. The measures have been further validated by other researchers and a pretest with 10 IS professionals. Reliability tests were performed for the collected data. The measures and their Cronbach's alphas are presented in Table 2. All Cronbach alphas exceed 0.6, which shows moderate to high reliability.

7. Casebase construction

The companies that are likely to have adopted EDI in the industries that have used EDI heavily were contacted and their EDI adoption states were confirmed. Publicly available company databases (available from Chollian network service) were used to search the companies. The structured interview was the main data collection method. Some questions about EDI controls may require sensitive information about security and data integrity. These questions can be better answered by the structured interview than by any other data collection method. One or two EDI managers simultaneously participated in the interview. They were believed to have sufficient knowledge about EDI implementation.

The survey instrument was validated via field interviews with ten EDI practitioners and four IS professors. Using the validated instrument, a total of 110 interviews were made. The respondents were EDI staffs or managers. The data were collected using structured interviews with EDI practitioner. The data used in validating the research model are gathered as part of a larger investigation concerning the EDI controls (Lee et al., 1998).

8. Performance of EDIGA

The performance of EDIGA is validated through comparison with a statistical method, regression analysis. In order to validate the use of GAs, Model 1 is compared with the

Table 3
Average of R^2 for models

Dependent variables	Models	
	Model 1	Model 2
Integration	0.22	0.15
Utilization	0.25	0.20
Improved relationship	0.43	0.3
Competitive advantage	0.38	0.33

following model

$$\text{Model 2}: \ Y = \text{const} + k_1C_1 + k_2C_2 + k_3C_3 + \ldots + k_nC_n$$

The 110 cases in the casebase were divided into two subsets; an estimation sample and a holdout sample. The estimation sample was used to build regression functions and estimate their parameters, as well as to construct the EDIGA knowledge base. The total number of cases was randomly divided into eleven subsets of 0 cases each. When each of these subsets was used as holdout sample one by one, the left over cases were used as estimation sample. That is, eleven pairs of holdout and estimation samples were composed each having ten and one hundred cases, respectively. In addition, four dependent variables of the implementation and performance were used to explore the stability of the results across different dependent variables.

After estimation sample is entered into EDIGA, the system retrieves the right mix of exponents that produce the lowest residual sum of square. The optimized value of exponent for each control from the estimation sample can then be used to predict the level of dependent variables (EDI implementation and performance) using holdout sample. The predictions were compared with the true values in the holdout sample to compute residual sum of square; the RSS were then averaged across the 11 holdout samples.

Similar procedures were applied to regression analysis (Model 2). Multivariate regression equations were constructed for the four dependent control variables and eleven sample sets. The predictive ability (i.e. the RSS) of these functions was determined by applying them to hold out samples.

The selection of good parametric value ranges is the issue of GA studies (e.g. Grefenstette, 1986), as the key to successful performance depends on determining a set of values such that there is a rapid convergence of optimization solution (Goldberg, 1989). For example, DeJong (1980) performed experiments to discover parameter values that might lead to good performance in numerical function optimization problems. He indicated that good performance demands a moderate population size (about 50), a moderately high crossover rate (about 0.60–0.75), and a low mutation rate (approximately inversely related to the population size). In this study, the standard genetic operators, crossover and mutation, are used with the following values: Population size = 50; Crossover rate = 0.5; Mutation rate = 0.06.

The predictive accuracy of Model 1 was compared to that of Model 2, multivariate linear regression analysis model. The holdout sample is used to check the “over learning” in GAs. The stopping conditions of learning should be adjusted not to result in solutions that are too specific to the patterns in estimation sample; GA is actually just memorizing the patterns. The stopping condition allows EDIGA to automatically stop when no improvement has been found in the last 200 scenarios. Four dependent variables of the EDI implementation performance were used to explore the stability of the results across different dependent variables. Using each estimation sample, GAs and regression analysis provided the estimation of the exponent and coefficient of the corresponding independent variables in Model 1. Regression functions were constructed for the four dependent control variables and 11 sample sets. The predictive ability of these functions was determined by applying them to holdout samples.

The RSS of Model 1 and Model 2 are given from the holdout sample (Table 2). The “predictive accuracy” of EDIGA (Model 1) for the level of dependent variables was compared with multiple linear regression analysis (Model 2). Table 2 shows the comparison results of two models. It turns out that the predictive accuracy of EDIGA outperforms that of linear regression analysis.

Model 1 has smaller RSS than Model 2 as shown in the paired *t*-test in Table 2. This shows that prediction accuracy can be significantly improved when the exponents of each variable are adjusted using GAs.

Another commonly used measure of the goodness of fit of a regression model is R^2. It is the square of the correlation coefficient between real value and estimated value of dependent variable (performance). R^2 of the equation in Model 1 is compared with that of linear equation in Model 2. R^2 of Model 1 and Model 2 are computed; the R^2 were then averaged across the 11 estimation samples.

The average R^2 of eleven holdout samples across four dependent variables are represented in Table 3. It can be seen that the average R^2 of Model 1 across eleven holdout

Table 4
t-Test of R^2

	Mean	N	Std. deviation	t-value of difference	d.f.	Significance (two-tailed)
Model 1	0.3182	44	9.045×10^{-2}	20.295	43	0.000
Model 2	0.2661	44	9.894×10^{-2}			

Table 5
Relative Importance of controls

EDI controls	Dependent variables			
	Integration	Utilization	Improved relationship	Competitive advantage
Internal formal application controls	1.45	20.15[a]	30.26[a]	0.12
Internal formal communication controls	−1.75	−0.16	40.13[a]	5.87
External formal VAN controls	2.52	−0.46	1.06	56.99[a]
External formal partner controls	−8.92	2.35	−0.13	−0.51
Internal informal controls by IS members	0.42	0.33	0.30	0.67
Internal informal controls by users	−2.74	−0.53	−1.92	−1.01
External informal controls for VAN	−2.75	0.87	−22.65	−55.02
External informal controls for partners	0.33	−3.88	0.30	−13.22
Internal automated application controls	8.57	0.38	0.70	0.30
Internal automated communication controls	−11.41	−5.20	0.32	−0.91
External automated controls by VAN	0.27	−0.22	21.18[a]	−2.50
External automated controls by trading partners	0.74	0.53	14.14[a]	7.29

[a] Indicates the controls that have the Relative Importance larger than 10.

samples are significantly higher than that of Model 2 for most of the samples and dependent variables (Table 4).

9. Control design example

An illustrative example is provided to show the reasoning process of control design in a computerized decision support system. First, separate analyses of the Relative Importance are performed for the cases of different independent and dependent variables (Table 5). GAs found the important EDI controls for each dimension of EDI implementation or EDI performance. The importance of 1 is adopted as the criteria to select important controls. Internal formal application controls, external formal VAN controls, and internal automated application controls have the higher importance than other controls when integration is a dependent variable. External formal partner is important for utilization of EDI systems. When improved relationship is a dependent variable, internal formal application controls, internal formal communication controls, external automated controls by VAN, and external automated controls by trading partners are important. For competitive advantage, internal formal communication controls, external formal VAN controls, and external automated controls by trading partners have the highest importance.

Second, a new company which has adopted (or will adopt) EDI are initially contacted and their EDI practitioners or managers are interviewed to obtain data about EDI controls, implementation, and performance. The data is then given to the EDIGA's interactive consultation system. Table 6 shows the new case.

The performance values of the current new case and the EDI system that implemented the controls recommended by EDIGA are compared to decide whether the system recommendation (coded value from Relative Importance) can be applied to current case. If performance value of the current case is higher than that of the EDI controls recommended by the system, the current state of EDI controls need not be modified as they are better than some criteria suggested by EDIGA.

When the dependent variable is integration (other cases of dependent variables can be similarly considered), the exponents and estimated coefficients of Model 1 are given as Table 7. The controls recommended by the system can be given from the Relative Importance suggested in Table 5 as follows:

Recommended Level of EDI Controls $= 1$,
if Relative Importance < 0.
Recommended Level of EDI Controls $= 3$,
if $0 \leq$ Relative Importance < 1.
Recommended Level of EDI Controls $= 5$,
if $1 \leq$ Relative Importance < 5.
Recommended Level of EDI Controls $= 7$,
if $5 \leq$ Relative Importance.

Performance value of the new case and the controls suggested by the system ("Recommended Levels of EDI

Table 6
New case

EDI Controls	New CASE
Internal formal application controls	6.5
Internal formal communication controls	2.5
External formal VAN controls	3.2
External formal partner controls	4.0
Internal informal controls by IS members	5.5
Internal informal controls by users	4.5
External informal controls for VAN	4.3
External informal controls for partners	3.1
Internal automated application controls	4.8
Internal automated communication controls	2.7
External automated controls by VAN	3.4
External automated controls by trading partners	2.3

Table 7
Exponents and coefficients of Model 1 (dependent variable is integration, constant in Model 1 is 18.05)

EDI controls	Exponents	Coefficients	Recommended levels of EDI controls[a]
Internal formal application controls	0.968	0.380	5.0
Internal formal communication controls	0.338	−1.099	1.0
External formal VAN controls	0.034	2.405	5.0
External formal partner controls	0.048	−8.340	1.0
Internal informal controls by IS members	0.833	0.131	3.0
Internal informal controls by users	0.012	−2.692	1.0
External informal controls for VAN	0.161	−2.198	1.0
External informal controls for partners	0.852	0.103	3.0
Internal automated application controls	0.136	7.099	7.0
Internal automated communication controls	0.005	−11.337	1.0
External automated controls by VAN	0.310	0.175	3.0
External automated controls by trading partners	0.154	0.595	3.0

[a] Value derived from the Relative Importance.

Controls" in Table 7) is 6.078 and 7.510. As the performance value of the controls recommended by the system is higher than that of the current case, the recommendation of the system, i.e. the "Recommended Levels of EDI Controls" in Table 7" are accepted and used in the design of controls. This new case updates the casebase and the future recommendation of EDIGA can reflect the change in casebase.

Management should consider giving a great deal of authority to the security department in establishing important EDI controls during system development. EDI managers and auditors should decide which detail control procedures are needed most. EDI system can be factored into subsystems for the evaluation of reliability of each subsystem and systematic detection of the most vulnerable subsystem. Each control procedure applies to different subsystem. A subsystem is a "unit" within the system that accomplishes a fundamental function such as top management, EDP management, systems development management, programming management, data administration, security administration, and operations management. If their reliability affects the overall system, more resources need to be invested for the audit and design of controls in the vulnerable subsystems. For example, if operations management is an important subsystem, the management might enforce its formal control procedures in the operations management in the area of job description. The boundary of their roles should be clearly defined so as not to cause any conflict over the liability of undesirable system outcomes such as fraud, altered messages, and unauthorized intrusions.

10. Conclusion

The study examines the application of GAs on the design EDI controls. Input is EDI controls and output is EDI implementation and performance. This study proposes a hybrid genetic optimizer to identify effective EDI controls—formal, informal, and automated controls—that lead to highest EDI implementation and performance. The empirical investigation consists of testing EDIGA, which employs a pattern directed search mechanism to produce the best fitting power model versus linear regression analysis as a method to evaluate the effectiveness of EDIGA. A comparison between the power model (i.e. EDIGA) based on GAs and the multivariate linear regression analysis model indicates that the GA-based approach is more appropriate in describing the relationship between EDI controls and EDI implementation and performance. The recommended level of EDI controls can be compared with new cases of EDI adopters and this will help them build appropriate level of controls. An illustrative example is provided to depict the reasoning process of control design using a simulated new case. EDIGA recommends the important EDI controls for each dimension of EDI implementation or EDI performance to the current new case. The recommendation can be accepted if the current case is not good in the design of EDI controls (i.e. if it has lower performance value than that of the system recommendation).

The main assumption of this study is that EDI controls affect EDI implementation and performance and the installation of them demands much resource. It is important that the management can be convinced of the effectiveness of the security and integrity controls and devotes much resource to make the control systems successful. The true potential of EDI is achieved when it is integrated with internal applications and linked with many trading partners replacing other traditional communication methods. However, the companies that are going to further integrate and expand EDI should examine whether they have included the appropriate design and development of effective controls as a part of the new EDI system.

The study performed a series of analyses of the difference in the design of controls for different dependent variables. Various combinations of EDI controls are needed for integration, utilization, improved relationship, and competitive advantage. Although EDI controls have been considered as important by practitioners, few studies verify the effectiveness of them on EDI implementation and performance. The application of EDIGA describes the decision support procedures when EDI auditors and mangers have to determine the mode and level of controls in the process of EDI implementation for overall high effectiveness of the control systems. Through these analyses, it is possible to demonstrate why some companies have lower risks when they appear to establish no apparent control procedures and mechanisms, or why frequent system abuses or errors break out in companies that have developed strong formal and technical procedures. When the risks are not predictable and cannot be eliminated entirely, the determination of important controls and their level become critical because they compensate for the lack of other controls.

The results of the study can help promote the usefulness of specific mode of EDI controls to management. Unless the new controls are validated, organizations will be reluctant to install them. Some may think that the controls will slow system response time and utilization, or that the costs outweigh the benefits to system integrity. The results of the study can attract management to invest appropriate resources to specific EDI controls. A weakness in critical controls may prompt the auditor to scrutinize the system further. This way, auditors can concentrate their resources on more important areas.

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