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Reliability Evaluation and Design of AICS: A Survey of Models and Experiments

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Abstract

The reliability of accounting internal control systems (AICS) is often viewed as a primary concern of auditors. Over the past three decades, several reliability models have been proposed for internal control. The main goal of these models is to provide an objective approach to evaluate the reliability of internal control systems. In addition, the models seek to assess the degree of audit reliance that can be placed on internal controls. This paper has a two-fold objective: (1) to present an overview of the descriptive and prescriptive reliability models developed for the design and evaluation of internal control systems, and (2) to discuss the effects of various factors on the reliability assessment. Furthermore, two methods to estimate process reliabilities are presented and several numerical examples are provided to show the detailed calculations of the reliability and economic efficiency of accounting internal control systems.

Key words: Accounting Internal Control, Accounting Reliability, Reliability Modeling

1. Introduction

Auditors have long recognized AICS as fundamental and indispensable to the performance of their duties. The degree of reliance they place on the client's system of internal control usually determines the depth and breadth of audit tests needed to verify the accuracy and completeness of transactions and account balances. At the same time, the failure of an internal control system cannot always be traced to a flaw in its design alone; even a well-designed AICS can be rendered ineffective if financial transactions are artfully structured with the blessings of management to circumvent the control system (Tipgos 2002; Zekany et al. 2004). Nevertheless, in the absence of coercive intervention by management, a reliable AICS can greatly help prevent occurrences of financial irregularities, accounting discrepancies and income manipulations. In addition, an AICS with high reliability will result in significant savings in audit time and cost.

To analyze the reliability of an accounting internal control system, the system is divided into a number of components (processes). As an example, Stratton (1981) divided the raw materials purchasing system into five processes: (1) daily review of raw material stock and preparation of purchase order if necessary, (2) preparation of receiving report at the time of order arrival, (3) Reconciliation of vendor's invoice, purchase order, and the receiving report, (4) investigation of discrepancy between vendor's invoice and receiving report if any exists, and (5) posting the raw material receipt to the raw material ledger. Srinidhi and Vasarhelyi (1986) defined the reliability of a process as the likelihood the process is correctly performed. They also defined the reliability of a system comprised of a network of interacting processes as the likelihood the output of the system is correct (free of errors). Since reliability is defined as a probability, reliability can only assume values between zero and one. If the reliability of a system is one, it implies the system output has no errors; otherwise, it has a certain percentage of errors identified by the reliability measure. The AICS reliability measure aggregates the reliabilities of all processes into a single value which describes the likelihood of error in the entire system.

This paper presents a review of the state-of-the-art reliability models reported in the literature to evaluate and design AICS. Two types of models are considered: descriptive and prescriptive (normative). *Descriptive models* seek to estimate the reliability of the AICS in operation in terms of its process reliabilities. If no AICS exists, or the one that exists is not highly reliable, descriptive models are used to estimate the reliability of alternative AICS configurations. The management should select the system (configuration) with the highest reliability, provided it is economically feasible. *Prescriptive (normative) models* are used to obtain the *optimal* configuration (design) of AICS for a given situation. Mathematical programming approach is used to formulate the objective function, which is typically maximizing the reliability of AICS, subject to existing budgetary and human resource constraints. An appropriate optimization software package is used to obtain the optimal solution for the mathematical model.

In our survey we first present two methods for estimation of process reliability (Section 2). This will be followed by descriptive models for AICS where the focus is on the methods that aggregate process reliabilities into one value — the system reliability (Section 3). In Section 4, prescriptive models to determine the optimal design of AICS are presented, and finally the experiments regarding factors influencing AICS reliability are reviewed in Section 5.

2. Estimation of the Process Reliability

2.1 Estimation of Process Reliability Using Historical Data

The basic principle behind this estimation approach is the use of relative frequency concept. As an example, Stratton (1994) used historical data to estimate reliabilities of processes in a sales order entry system. As will be discussed in Section 3.3.2.2, the AICS was divided into 13 processes and required data were collected (See Table 4). The relative frequency concept is then used to estimate the process reliabilities. For example, the sample size for the first process in the table was 300. The process was correctly performed 299 times which yielded a reliability measure of 299/300 = 0.997.

2.2 Estimation of Process Reliabilities Using Auditor's Judgment

Srinidhi and Vasarhelyi (1989) developed a method to help auditors estimate process reliabilities. They identified factors that influence process reliabilities such as: (1) degree of segregation of duties as discussed by Srinidhi (1994), (2) degree of centralization of the hierarchy in the firm, and (3) reward/punishment system within the firm relative to errors. In addition, they considered personnel and task related factors that influence process reliabilities. The personnel factors are competence of employees, their awareness of the client firm procedures, and integrity of personnel. The task related factors are complexity of the task and average time devoted to perform the task. These factors as well as other relevant factors are used to aid the auditors in assessing the probabilities of different events. Such probability estimates include the probability of unintentional error committed by each employee and the probability that an employee detects an error. This information is used to estimate the process reliability.

3. Descriptive Models for AICS

This Section presents a comprehensive survey of descriptive models to evaluate AICS reliability. The descriptive models determine the reliability of an existing AICS. They can also be used to find the reliabilities of alternative AICS configurations to identify a more reliable system. Descriptive models may not determine the *optimal* system configuration since all possible alternatives are not usually examined. However, in many situations descriptive models provide a configuration with satisfactory reliability. In this section, descriptive models are classified based on the method used to combine process reliabilities into system reliability.

3.1 Reliability Models Based on Markov Process

This approach assumes that the quality (state) of accounting documents changes over time during processing as it goes from one operator to the next. Each change of state is called transition. The transition probability matrix presents the probabilities of all possible transitions. The quality of the documents that arrives to an operator may or may not change after the operator completes the process. The quality of the output depends on the quality of the input, the operator's skills, and the characteristics of the transition (operation). Given the quality of the incoming documents and the transition probability matrix of each clerk, one can determine a sequence of state vectors describing the states of the documents as they go through processing. It should be noted that each operator has some propensity to introduce errors and some to identify and eliminate errors. The state vectors help auditors determine the most frequent types of errors and provide a quality improvement plan for error reduction. Such plans may include further training of employees, inclusion of additional control steps, etc.

Yu and Neter (1973) who are often regarded as the pioneers in the field of AICS reliability modeling used the Markov process approach. They studied a manual payroll system consisting of the basic payroll processes such as time card punching, foreman's review, controller's review, check preparation, the use of an imprest account, and monthly reconciliation of the bank account. They also considered two types of errors in accounting documents: 1) monetary errors, and (2) nonmonetary errors, i.e. any errors in name, address etc. Four states correspond to the errors: (1) state S_1, No errors; (2) state S_2, Monetary errors only; (3) state S_3, Nonmonetary errors only; and (4) state S_4, Both types of errors, at any time during processing. For each state, two binary variables are used to represent the presence or absence of the monetary and nonmonetary errors, respectively. Various system states are represented by $S_1 = (0 \ \ 0)$, $S_2 = (1 \ \ 0)$, $S_3 = (0 \ \ 1)$, and $S_4 = (1 \ \ 1)$. The transition probability p_{ij} is the probability that the system state changes from S_i to S_j during processing. For example, consider a payroll clerk performs an operation on a document. If the document received by the clerk has no error (state S_1), the document after processing will either have no errors (state S_1) with probability p_{11}, have monetary errors (State S_2) with probability p_{12}, have nonmonetary errors (State S_3) with probability p_{13}, or have both errors (State S_4) with probability p_{14}. The transition probabilities generally depend on the clerk's competency, training and experience. The estimation of the transition probabilities for a payroll clerk is based on historical data pertinent to the number of documents received by the clerk in each of the four states. The fraction of documents (relative frequency) that had no errors when received and remains without errors after the clerk completes the process is the estimate for p_{11}. In the same fashion, the fraction of documents that had no errors when received and have monetary errors after completion is an estimate for p_{12} and so on. The following probability matrix presents the transition probabilities among various system states for Payroll Clerk A:

$$P = \begin{pmatrix} p_{11} & p_{12} & p_{13} & p_{14} \\ p_{21} & p_{22} & p_{23} & p_{24} \\ p_{31} & p_{32} & p_{33} & p_{34} \\ p_{41} & p_{42} & p_{43} & p_{44} \end{pmatrix}$$

Example 1: Assume the status of all documents received at one point of time by the payroll clerk is described by the input vector W_I = (0.966 0 0.034 0). The vector is interpreted as 96.6% of the documents are in state S_1, 3.4% of the documents are in state S_3, and none are in the other states. The output vector, W_O, describing the status of the documents after processing by Payroll Clerk A is the result of multiplying W_I by the transition matrix shown in Yu and Neter (1973):

$$W_O = W_I \cdot P = (0.925 \quad 0 \quad 0.075 \quad 0)$$

The output vector shows that 92.5% of the documents will have no errors and 7.5% will have nonmonetary errors only. The process is continued until the last operation. As a result, a sequence of output vectors are obtained showing how the quality of the documents changes among the four error states as they are processed through the system. Assume the following terminal vector, W_t, is obtained for an AICS (a sequence of individual accounting processes):

$$W_t = (0.992 \quad 0.002 \quad 0.004 \quad 0.002)$$

The first value, 0.992, is the probability the system is free of error, which is the system reliability. The second value, 0.002, is the probability the system has monetary errors only; the third value, 0.004, is the probability the system has nonmonetary error only; and the fourth value, 0.002, is the probability the system has both types of errors.

Since some operations may not be connected in series, Yu and Neter (1973) introduced modifications for cases in which the operations are branching or merging. Their model can be used to determine and evaluate the reliability of an existing AICS, or to develop and design a reliable one if none exists. Since designing an internal control system may involve some changes in the existing system's configurations, this model can also evaluate the effect of the design changes on the system reliability. For example, a company may want to drop a control measure or replace it with another. The model should be applied before and after the design change and a comparison should be made between the two terminal vectors.

Example 2: The effect of design change in an AICS

Consider the following two terminal vectors:

Before the design change: $W_b = (0.992 \quad 0.002 \quad 0.004 \quad 0.002)$

After the design change: $W_a = (0.871 \quad 0.056 \quad 0.042 \quad 0.031)$

In the above situation it is evident that the change in the design of the AICS is going to reduce the system reliability and therefore it is not recommended.

Grimlund(1982) extended the work of Yu and Neter (1973), Cushing (1974), and Felix and Grimlund (1977) to allow auditors to incorporate uncertainties about the error rate of each process in the AICS. He considered two system states: (1) in-compliance state, and (2) not-in-compliance state, both of which may contain monetary and/or non-monetary errors. The not-in-compliance state (error state) can be divided into several error states based on the modeling objectives such as non-monetary error state, monetary error state, etc. As an alternative to the assumption that error probabilities were given values as considered in Cushing's model, Grimlund treated each error probability as a random variable. This assumption holds when the auditors are uncertain about the error rates.

3.2 Models Based on Control Step Performance

The models presented in this section estimate the AICS reliability based on: (1) the probability the process is performed correctly and (2) the conditional probabilities the control step is capable of detecting and correcting each type of error. The approach relies heavily on historical data to estimate the corresponding probabilities. The models also determine the reliability of AICS corresponding to each error type (the likelihood the accounting document is free of that error type). Auditors can use this information to decide on the depth of the audit tests. If certain error types are more likely to occur, management should prepare a continuous improvement plan to reduce such errors. The models can also determine the economic efficiency due to the use of a control step, which is the difference between the cost of the AICS when a control step is performed (cost of implementing the control step) and the cost when such a step is ignored (cost of errors).

3.2.1 Cushing's Models

An AICS is intended to prevent losses from intentional and unintentional errors in data processing. Cushing (1974) developed mathematical models to evaluate the design and cost/ benefits of AICS. He considered the example of posting cash receipts to customers' accounts in an a typical business organization, where intentional and unintentional errors may include: (1) a discrepancy between the amount of cash received and the amount posted to the accounts receivable control account,

(2) posting of a receipt to a wrong customer account, (3) overpayment by the customer, and (4) embezzlement of cash receipts. Possible control measures include: (1) clerical review and reconciliation of individual remittances from each customer account prior to its posting by the accounts receivable clerk, (2) separating the function of the accounts receivable clerk and the cashier, (3) checking control totals by the accounts receivable clerk subsequent to posting a batch of receipts, (4) comparison of data provided by the accounts receivable clerk with that provided by the cashier prior to posting by the general ledger clerk, and (5) periodical preparation of a bank statement reconciliation by an independent employee.

Cushing (1974) modeled four types of AICS: (1) single control – single error, (2) single control – multiple errors, (3) multiple controls – single error, and (4) multiple controls – multiple errors. The focus of our review is on the first model since it contains the basic concepts, the other models are just extensions of this model. Figure 1 illustrates a tree diagram for the Single Control - Single Error System. The first two branches indicate that the process is either correctly performed (process OK) or incorrectly performed (Error in process). Two branches emerge from each of these original branches, representing whether the control step signals an error or not. The two branches that follow represent whether or not a corrective action has been taken. System reliability is developed in terms of the following parameters:

p probability that the process is correctly performed,

$P(e)$ probability that the control step detects an error, given that one exists,

$P(s)$ probability that the control step does not detect an error, given that none exists,

$P(c)$ probability that the control step corrects the error, given that one exists and has been detected,

$P(d)$ probability that the control step does not make any error correction, given that it detects an error when none exists.

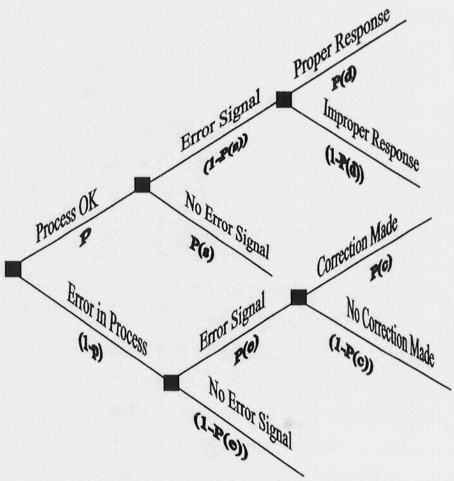
The AICS reliability is expressed as: $R = pP(s)+p(1\text{-}P(s))P(d)+(1\text{-}p)P(e)P(c)$

The system reliability if a control step is not performed is $R' = p$.

> **Example 3:** If the probability the process is correctly performed, $p = .8$, the probability the control step can detect an error given that one exists, $P(e) = .95$, the probability the control step does not detect an error given that none exists, $P(s) = .9$, the probability the control step has corrected an error given that one exists and has been detected, $P(c) = .98$, and the probability the control step has not corrected an error given that it detects an error when none exists, $P(d) = .99$, the reliability of the AICS, R, is:
>
> $R = .8(.9) + .8(1\text{-}.9)(.99) + (1\text{-}.8)(.95)(.98) = .9854$
>
> If a control step is not performed, the system reliability is $R' = p = .8$.
>
> Therefore the system reliability increases from 80% to 98.54% (an increment of $R - R' = 18.54\%$) due to the use of a control step.

Figure 1

Tree Diagram for the Single Control - Single Error Case



The economic efficiency due to the use of a control step can be determined as the difference between the cost of the AICS when a control step is performed and the consequential cost when such a step is omitted. If Ce is the average cost of an uncorrected error, then the expected total cost of errors in the process when the control step is not performed is $Ct = (1-p)Ce$. Assume Cc is the cost of performing the control procedure each time the process is executed and Cs is the average cost of searching and correcting an error when the control step signals an error, if in fact one exists. The expected total cost of errors in the process when the control step is performed would be:

$$Ct' = Cc + (1-R)Ce + [p(1-P(s)) + 1(1-p)P(e)]Cs$$

Example 4: Assume in the previous example, the cost of performing the control procedure is $Cc = 2$, the average cost of searching and correcting an error, $Cs = 3$, and the average cost of uncorrected error, $Ce = 20$.

Then, the total cost of errors in the process, when the control step is not performed, is $Ct = (1-p)Ce = (1-.8)(20) = 4$. Conversely, when the control step is performed, the total cost of errors in the process is:

$Ct' = Cc + (1-R)Ce + [p(1-P(s)) + (1-p)P(e)]Cs = 2 + (1-.9854)20 + [.8(1-.9) + (1-.8).95]3 = 3.102$

The net advantage resulting from the use of the internal control step= 4 - 3.102 = .898.

3.2.2 Feedforward and Maintainability Concepts

Ishikawa (1975) indicated that the models presented in Cushing (1974) for the design and evaluation of AICS do not make use of the feedforward concept as discussed in Ishikawa (1972), and in Ishikawa and Smith (1972). He also suggested that the concept and techniques associated with maintainability be taken into consideration. *Maintainability* aims at avoiding the occurrence of errors and minimizing error correction time rather than detecting and correcting an existing error. It should be considered within an explicit time frame. Once the internal control manager determines the maximum allowable time interval for correcting an error, the probability that maintenance is performed within that time frame becomes a control measure along with its associated cost. Ishikawa (1975) provided examples of preventive maintenance and actions as applied to AICS, which included proper training to reduce the likelihood of committing errors, proper incentive plans, promotion of ethics to prevent embezzlement of cash receipts, and removal of an untrained clerk before an error occurs.

3.2.3 Modes of Control

Cushing (1975) explained three modes of control, which can be applied to a process either individually or in combination. These modes are: (1) structural or programmed control, (2) feedforward control, and (3) feedback control. *Structural or programmed control* is primarily internal in nature. It does not rely upon nor is it designed for regular monitoring of inputs or outputs. *Feedforward control* relies upon regular monitoring of process inputs to predict and, therefore, prevent future deviations in the process and its output. *Feedback control* relies upon regular monitoring of process outputs to identify deviations indicating the need for corrective action. The three control modes are complementary to one another and should not be viewed as alternatives. The selection of the best set of control procedures is governed by: (1) simplification of the control systems and (2) minimization of the undetected errors' costs.

3.3 Models Based on Process Reliabilities

This section reviews the descriptive models that estimate the AICS reliability in terms of process reliabilities. The reliability of any process in AICS can be estimated as discussed in Section 2. The relationships among different processes can be presented graphically by *block diagrams*. In a block diagram, processes which are performed in sequence are shown by blocks in series and dual processes are presented by blocks in parallel. Different system configurations are discussed in this section along with the procedure to identify the most important process in the AICS.

3.3.1 Calculation of System Reliability

In this section, block diagrams are used to determine the system reliability for different AICS configurations in which the system may or may not have redundant components. *Redundancy* is generally recognized as an approach to improve the reliability of a system (Mohamed et al. 1993). It refers to the inclusion of alternative components to help the system operate in case of failure of one or more of its components. Elsayed (1996, Page 118) defined redundancy as "the use of additional components or units beyond the number actually required for satisfactory operation of a system for the purpose of improving its reliability". Common examples of redundancy in engineering are standby or backup generators and computers. AICS also may include dual procedures that perform the same function. A redundant component is graphed in a reliability block diagram as a parallel component. A non-redundant component on the other hand, is graphed distinctly in series. Consider an AICS which is comprised of *n* processes in series as presented in Figure 2. If we add one redundant component for each process, the AICS can be explained as shown in Figure 3. Alternatively, we may add a redundant system for the entire AICS as presented in Figure 4.

Figure 2

Block Diagram of a Series System of *n* Component

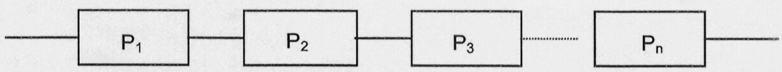


Figure 3

Component Redundancy

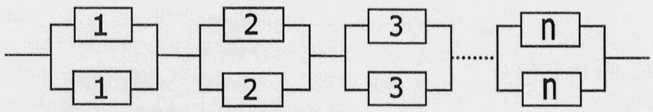
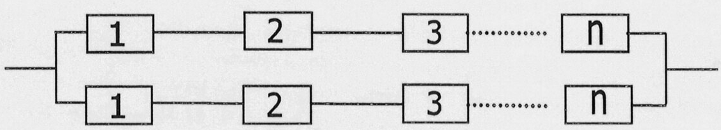


Figure 4

System Redundancy



If we assume that the AICS has n processes in series, each with the same reliability p, the reliability of the AICS as shown in Figure 2 will be p^n. To improve the system reliability we may resort to either redundant components or redundant systems, or a combination of both. The reliability of the system shown in Figure 3 is and the reliability of the system shown in Figure 4 is Elsayed (1996, p 77-79) demonstrated that a system with component redundancy (Figure 3) always has higher reliability than one with system redundancy (Figure 4). This concept should be taken into account when designing or improving upon an AICS.

Example 5: Consider a system of 5 processes in series, each with the same reliability of 0.92. If the system has no redundancy as shown in Figure 2, the system reliability would be $R= (0.92)^5 = 0.659$. For the system with component redundancy as presented in Figure 3, the reliability is calculated as $R= [1-(1-0.92)^2]^5 = 0.968$. Whereas in the case of system redundancy as shown in Figure 4, the system reliability would be $R= 1-(1-0.92^5)^2 = 0.884$. This verifies the fact that a system with component redundancy is preferable to one with system redundancy.

3.3.2 Structure Function, Structure Importance and AICS Reliability

The *structure function* is a useful tool to describe how n processes are related to form a system (Leemis 1995, Pages 15-16). It identifies the system status (whether or not the transaction is free of error) in terms of the status of the individual processes in the system. Since some processes have higher impact on the system performance, the *structure importance* of a process measures the impact of that process on the system structure function. The following two subsections present two case studies showing the applications of the above concepts in accounting.

3.3.2.1 Modeling a Raw Material Purchasing System

Stratton (1981) developed a mathematical model to determine the reliability of a typical system of purchasing raw materials. The system exerts various controls as a material purchase transaction is performed. Table 1 summarizes the steps in the transaction, a review of which was presented earlier in Section 1.

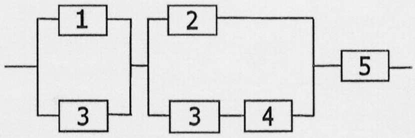
Table 1
Processes of the Raw Material Purchasing System

Process	Process Description
1	Purchasing agent prepares a purchase order
2	Receiving personnel prepares receiving report
3	Accounts payable clerk reconciles vendor's invoice, purchase order and receiving report
4	Purchasing agent investigates discrepancy between vendor's invoice and receiving report
5	Inventory clerk posts raw material receipts to raw material ledger

Figure 5 shows the reliability block diagram of the above system. It presents all processes and the way they are arranged. Parallel processes imply redundancy; for example, since process 3 reviews the work performed in process 1, they are in parallel.

Figure 5

Block Diagram of the Raw Material Purchasing System



The status of process *i* in terms of whether it was performed correctly or not, can be represented by a binary random variable X_i, where $X_i = 1$ indicates the process was performed correctly and $X_i = 0$ otherwise. For example, when performing process 1 (purchasing agent prepares a purchase order), $X_1 = 1$ when the order is prepared correctly and $X_1 = 0$ otherwise. The *structure function* of the above system is:

$$\phi(\underline{X}) = [1-(1-X_1)(1-X_3)][1-(1-X_2)(1-X_3X_4)]X_5,$$

where vector $\underline{X} = (X1, X2,..,X5)$ describes the status of each process in the system. For example $\underline{X} = (1, 1, 0, 1, 0)$ implies that processes 1, 2, and 4 were performed correctly and processes 3 and 5 had errors. The value of $\phi(\underline{X})$ is one when the AICS is functioning correctly and zero otherwise.

For any process, the *structure importance* measures the impact of the process on the system structure function. Assuming the goal is to upgrade processes with the highest impact on the system, improvements should be made on the processes with the largest structural importance (Leemis 1995, p 22-23). Assume $\phi(\underline{X}) \setminus X_i = 1)$ represents the value of $\phi(\underline{X})$ when $X_i = 1$ and $\phi(\underline{X}) \setminus X_i = 0)$ represents the value of $\phi(\underline{X})$ when $X_i = 0$. If *n* is the number of processes in the AICS, the structure importance of process *i*, $I_\phi(i)$, is:

$$I_\phi(i) = \frac{1}{2^{n-1}} \sum_{\underline{X} \setminus X_i = 1} [\phi(\underline{X}) \setminus X_i = 1) - \phi(\underline{X} \setminus X_i = 0)]$$

Example 6: For the raw material purchasing system as described in Table 1 and Figure 5, the structure importance of processes 1, 2, 3, 4, and 5 are calculated as: $I_\phi(1) = 1/8$, $I_\phi(2) = 2/8$, $I_\phi(3) = 2/8$, $I_\phi(4) = 1/8$, and $I_\phi(5) = 4/8$. A sample calculation for the structural importance of process 5 is shown in Table 2. The above results show that process 5 has the highest structural importance, while the remaining processes are of lesser importance.

Table 2
Sample Calculation for the Structural Importance of Process 5 for the System Shown in Example # 6

Process	Process states when x_5=1	$\phi(\underline{X})\backslash X_5 = 1) - \phi(\underline{X} \backslash X_5 = 0)$
5	(0, 0, 0,0,1)	0 - 0 = 0
	(1, 0, 0,0,1)	0 - 0 = 0
	(0, 1, 0,0,1)	0 - 0 = 0
	(0, 0, 1,0,1)	0 - 0 = 0
	(0, 0, 0,1,1)	0 - 0 = 0
	(1, 1, 0,0,1)	1 - 0 = 1
	(0, 1, 1,0,1)	1 - 0 = 1
	(0, 0, 1,1,1)	1 - 0 = 1
	(1, 0, 1,0,1)	0 - 0 = 0
	(0, 1, 0,1,1)	0 - 0 = 0
	(1, 0, 0,1,1)	0 - 0 = 0
	(1, 1, 1,0,1)	1 - 0 = 1
	(0, 1, 1,1,1)	1 - 0 = 1
	(1, 0, 1,1,1)	1 - 0 = 1
	(1, 1, 0,1,1)	1 - 0 = 1
	(1, 1, 1,1,1)	1 - 0 = 1
$I_\phi(5) = \frac{1}{2^{n-1}} \sum_{\underline{X}\backslash X_5} [\phi(\underline{X} \backslash X_5 = 1) - \phi(\underline{X} \backslash X_5 = 0)] = \frac{8}{16}$		$\sum_{\underline{X}\backslash X_5} [\phi(\underline{X} \backslash X_5 = 1) - \phi(\underline{X} \backslash X_5 = 0)] = 8$

Assume that the reliability of an AICS is described by $R_s(\underline{P})$ where vector P presents the reliabilities of processes in the system. For example, P = (0.92 0.97 0.90 0.95 0.91) indicates that there are five processes in the system with the reliabilities shown in the vector. An unbiased estimate of the AICS reliability can be determined by calculating the expected value of the system structure function $R_s(\underline{P}) = E[\phi(\underline{X})]$. Stratton (1981) simplified the raw material purchasing example shown before in Figure 5 according to the following assumptions:

(1) Process 5 in the system is always performed correctly, therefore process reliability is 1,

(2) Process 4 in the system is always faulty, as a result process reliability is zero.

This enables us to disregard process 5 or excluded it from the block diagram since this exclusion will not change the system reliability. In addition, we may completely remove the branch containing process 4 since this branch will never function successfully. Figure 6 shows the simplified block diagram. The AICS reliability function for the revised block diagram is: $R_s(\underline{P}) = P_1P_2 + P_3P_2 - P_1P_2P_3$

Example 7: The structural importance of the three processes in the simplified block diagram are calculated as: $I_\phi(1) = \frac{1}{4}$, $I_\phi(2) = \frac{3}{4}$, and $I_\phi(3) = \frac{1}{4}$. The above result shows that for the simplified system, process 2 is the most important and processes 1 and 3 are of less importance.

Figure 6

Simplified Block Diagram of the Raw Material Purchasing System

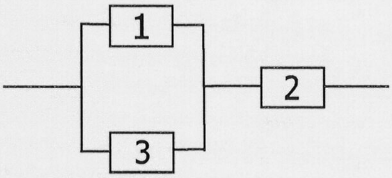


Table 3 shows the calculations for the reliability of each process as well as the system reliability for the simplified material purchasing system.

Table 3
Process Reliability Estimates and System Reliability Calculation

Process Sampled	Sample Size	Error Detected	Error Fraction	Process Reliability Estimates
1. Purchase order preparation	167	7	0.042	0.958
2. Receiving Counts	166	10	0.060	0.940
3. Accounts-payable control	166	6	0.036	0.964

The system reliability is:
$R_s(\underline{P}) = P_1P_2 + P_3P_2 - P_1P_2P_3$ = (0.958)(0.940)+(0.964)-(0.940)(0.964)=0.939

3.3.2.2 Modeling a Sales Order Entry System

Stratton (1994) presented another application of AICS reliability modeling using data from a field study of a sales order entry system of a medium-sized firm. The activity initiating the order entry cycle was the sales entry made either by phone or mail. The cycle ended with the posting of the transaction entry to the accounts receivable file. Under Stratton's model, the sales order entry system was divided into thirteen processes (activities) as shown in Table 4.

Table 4 Process (Activity) Descriptions and Reliability Estimations				
	Description	**Sample Size**	**Errors**	**Process Reliability**
11	Sales clerk types shop order.	300	1	.997
12	Sales clerk forwards copies 4 & 5 to shipping.	300	1	.997
13	Sales clerk enters quantity shipped, prices, and freight charges on copies 1, 2, 3 of shop order.	300	8	.973
14	Sales clerk forwards copies 1, 2, 3 and P.O. to accounting department.	300	1	.997
21	Shop supervisor reviews shop order.	N/A	N/A	.80
22	Quantity and date shipped entered on copies 4 and 5.	300	4	.987
23	Supervisor reviews shop order for propriety after order completed.	N/A	N/A	.950
24	Shop order # 4 forwarded to sales clerk.	300	1	.997
31	Computer operator checks pricing.	N/A	N/A	.990
32	Computer operator makes list of unit prices and quantities shipped.	252	2	.992
33	Computer operator inputs price and quantity, freight charges into computer.	160	1	.994
34	Computer operator compares batch total from operation 32 to similar figure from output from computer run.	252	1	.996
41	Computer updates run of accounts receivable.	N/A	N/A	1

The system block diagram shown in Figure 7 presents all activities and their arrangement. The AICS is the sum total of all activities divided into four modules. Each module contains a group of activities. Since no module reviews the work performed in another module, all modules are arranged in series.

The structure functions of module j, $\phi_j(\underline{X})$, where j = 1,2,3,4, are:

$$\phi_1(\underline{X}) = 1-\{1-[1-(1-X_{11})(1-X_{21})]X_{22}\}[1-X_{23}],$$

$$\phi_2(\underline{X}) = X_{12}\, X_{24}\, X_{14}\,,$$

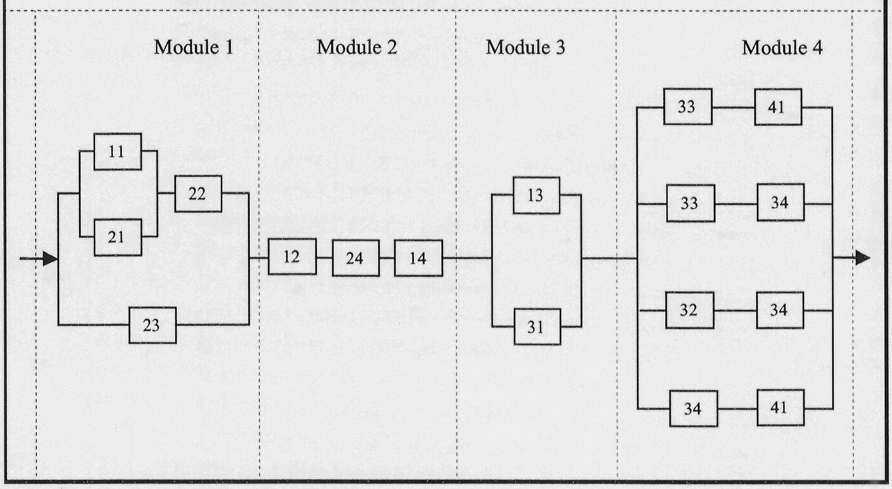
$$\phi_3(\underline{X}) = 1-(1-X_{13})\,(1-X_{31}) \text{ and}$$

$$\phi_4(\underline{X}) = 1-(1-X_{33}X_{41})\,(1-X_{33}X_{34})\,(1-X_{32}X_{34})\,(1-X_{34}X_{41}).$$

The structure function $\phi_j(\underline{X})$ represents the status of the work performed in module j. If $\phi_j(\underline{X}) = 1$, it implies the work performed in module j is done correctly, and

Figure 7

Reliability Network for Order Entry System



$\phi_j(X) = 0$ implies it is done incorrectly. It should be noted that the structure function of the above AICS is the product of the structure functions of all four modules since they are in series.

An estimate for the reliability of each process in the above-mentioned example can be obtained as shown in Table 4. Stratton estimated the reliabilities of processes 21, 23, 31, and 41 through in-depth interviews with the appropriate supervisors. The reliability of the AICS is obtained as 0.990. This means 99% of the time the order entry system operates successfully. Stratton (1994) also calculated the structural importance of each process and ranked them. In addition, he presented different scenarios for improving the reliability of the order entry AICS.

The main drawback of Stratton's (1981 and 1994) models is that they did not differentiate between performance components and control components. Stratton utilized the concept of redundancy the same way it was used in engineering reliability. For example, in a system of two parallel components, each component is redundant to the other one. However, in an AICS comprised of two parallel processes, typically, one process is a performance process while the other is a control process. This makes the control process a redundant one whereas the performance process is not considered as redundant.

3.3.3 Performance and Control Processes

Srivastava and Ward (1983) as well as Srivastava (1985) classified the processes in the AICS into two categories: (1) *performance processes*, which complete the tasks but cannot perform any error correction, and (2) *control processes*, which are designed to prevent, detect and correct errors in the input information. Srivastava and Ward developed a model to find the AICS reliability which included *n* identical control processes in series. Their model assumed the reliability of the document which entered the first control process was known and calculated its reliability after the completion of *n* control processes, which in turn is the reliability of the AICS.

3.3.4 Model Based on Mean and Variance of Process Reliabilities

Soliman (1979) developed a model that determined the AICS reliability in terms of the mean and variance of the reliability of each process. The model assumes that processes in the system are independent (occurrence of error in one process does not influence the occurrence of error in another). Soliman also showed that if processes are dependent, the model is likely to underestimate the system reliability. However, this conclusion, as observed by Knechel (1983), was tempered by the fact that Soliman considered dependency only between two components, and assumed process reliabilities to be low. Knechel's article also included a comprehensive literature survey of the application of quantitative models in the review and evaluation of AICS.

4. Prescriptive Models for AICS Reliability

This section presents prescriptive (normative) models for the AICS reliability. The models determine the optimal allocation of control components to maximize the AICS reliability subject to predetermined budgetary and manpower constraints. They can also determine the optimal assignment of individuals to activities. Each individual is either assigned to one task or combination of tasks. Factors such as the level of expertise of individuals, suitability of combining tasks, and the impact on AICS reliability are considered. Section 3.1 presents optimization models to determine the optimal allocation of control components in AICS and Section 3.2 presents optimization models to obtain the optimal assignment of tasks to individuals. The main objective of those models is to maximize the AICS reliability.

4.1. Optimal Allocation of Control Components

Belkaoui and Henin (1977) sought to revise Cushing's models which were based on the assumption that the control procedures are either all active or all inactive. Their revision provided for allowing the controller choose the best set of control procedures as well as determine their order and optimal number for an AICS. Their effort led to the development of two mathematical models: (1) maximizing the AICS reliability subject to budgetary constraints, and (2) minimizing the expected cost of control and error subject to a desired level of system reliability. The objective function and constraints of the models were derived from Cushing's multiple controls – multiple errors reliability and cost models.

Belkaoui and Henin (1977) demonstrated that at each control stage their optimization models can determine whether or not a control step should be applied. They employed a binary (zero-one) integer linear programming approach. Decision variables of the models would take a value of 1 should a control step be performed, and a value of zero, otherwise. They revised Cushing's models by including the binary variables. They also presented an optimization algorithm using implicit enumeration by the branch and bound technique to determine the optimal solution of their models. Their solution algorithm eliminated certain types of control if the cost of control exceeded the derived benefits at a specific stage. This elimination procedure reduces the number of iterations the algorithm has to go through before reaching the optimal solution. In the final solution, the optimal value of a decision variable (1 or 0) would determine whether or not a control step, at a given stage, should take place. In addition, they proposed a possible extension to their algorithm to identify the optimal order of controls.

Hamlen (1980) presented a mixed integer programming model for the design of an effective AICS. The model considered a given set of potential control steps, each of which was assigned an error reduction rate for each error type. Then, the model identified the optimal combination of controls that would minimize the total system cost subject to constraints of error reduction goals set by management as well as restrictions on the use of controls. This model can also be used by external auditors to evaluate the existing AICS. Two versions of this model were proposed: (1) a model with zero-one decision variables assuming that each control step is either used all the time or not used at all, and (2) a model with continuous decision variables assuming that each control step can only control a fraction of the processes. For example, the control step that separates duties of accounts receivable clerk and cashier is presented as a zero-one variable because the step is either implemented or not. On the other hand, the independent reconciliation of receipts with credits in the accounts receivable subsidiary accounts is included as a continuous variable because all receipts may not to be reconciled. Hamlen used the mixed zero-one integer programming algorithm as proposed by Loehman et al. (1969) to find the optimal solution of the models.

4.2 Optimal Assignment of Tasks

It is generally acknowledged that segregation of accounting tasks has a great impact on AICS reliability. The reliability of an AICS increases if tasks are performed independently (segregated). The disadvantage of task segregation is that manpower, training and supervision requirements are much higher. Thus management has to decide about the tradeoff between AICS reliability and forementioned costs. Srinidhi (1988) developed a mathematical model to determine the optimal assignment of tasks to individuals that would maximize system reliability subject to manpower constraints. He showed the AICS reliability is higher if each task is assigned to an independent employee and lower when multiple tasks are assigned to an employee. He used the symbol R for AICS reliability when all tasks were segregated, and R_1 when tasks i and j were combined. The ratio of $R_1/R = d_{ij}$ is the degradation of AICS reliability due to the combination of tasks i and j. The range of degradation values is from 0 to 1. A value of 1 means no degradation and a value of 0 means complete degradation. The degradation matrix $D = \{d_{ij}\}$ was developed by in-depth interviews with auditors. They were presented with different scenarios of task combination patterns and asked to provide estimates of the system reliabilities with and without task combination. The ratio of the two reliability estimates determined the degradation corresponding to a task combination pattern. Following this approach, one can estimate all the elements of the degradation matrix D. Srinidhi defined the following decision variables:

$$a_{ij} = \begin{cases} 1 \text{ if task } j \text{ is assigned to employee } i \\ 0 \quad \text{otherwise} \end{cases}$$

and:

$$x_{jk} = \begin{cases} 1 \text{ if tasks } j \text{ and } k \text{ are combined} \\ 0 \text{ if tasks } j \text{ and } k \text{ are segregated} \end{cases}$$

where $x_{jj} = 1$ for all j.

Srinidhi also defined matrix $B = \{b_{ij}\}$ as the assignment possibility (feasibility) matrix. Elements of matrix b_{ij} are defined as:

$$b_{ij} = \begin{cases} 1 \text{ if task } j \text{ can be assigned to employee } i \\ 0 \quad \text{otherwise} \end{cases}$$

If the number of employees is m and the number of tasks is n, the mathematical model is:

$$\text{Maximize } R \prod_{j,k} [1 - x_{jk} + d_{jk} x_{jk}]$$

$$\sum_k x_{jk} \leq 2 \text{ For all } j = 1, 2 \ldots, n$$

$$\sum_j \sum_k x_{jk} = 3n - m$$

$$x_{jk} = \sum_{i=1}^{m} a_{ij} a_{jk} \text{ For all j, k}$$

$$a_{ij} b_{ij} = a_{ij} \text{ For all i, j}$$

$$\sum_{i=1}^{m} a_{ij} = 1 \text{ For all j}$$

The major drawbacks of this model are that it does not include the duration of each activity and the time availability of employees.

5. Experimental Studies

5.1 Effects of Segregation of Duties

The above mathematical model provides the optimal segregation of tasks. The importance of segregation of duties in AICS has been the focus of attention of many researchers. For instance, Nichols (1987) recognized it as the most important variable in the models developed to evaluate the reliability of AICS. Arens and Loebbecke (1991) acknowledged it as an essential factor to ensure a reliable AICS. Srinidhi (1994) concluded from a review of several studies that segregation of duties has the most influence on AICS reliability. Srinidhi conducted an experimental study to test the validity of two propositions related to the segregation of duties: (1) auditors place significantly lower reliance on an AICS with duty combinations than on one for which duties are fully segregated, and (2) Functional classification explains a significant portion of variations in auditor judgments on duty combinations. He selected a sample of forty auditors and asked them to evaluate the reliability of an AICS for a variety of duty combination patterns. ANOVA and t-test were used to find whether there was significant statistical evidence in favor of the above propositions. The results confirmed the validity of both propositions.

5.2 Effects of Auditors' Background/Experience and Task Complexity

Nanni (1984) studied the effects of auditors' background on their judgments. A series of AICS cases were presented to experienced auditors for their evaluation. The objective of the research was to determine which background variables played a major role in auditors' evaluations. Nanni found that firm affiliation, auditors' rank/years of experience, and control evaluation experience were among the variables that influenced auditors' judgments the most.

Abdolmohammadi and Wright (1987) examined the effects of experience and task complexity on audit judgments. They considered three cases from actual audit engagements consisting of six audit tasks, which were classified as structured, semi-structured, and unstructured based on the degree of task complexity. Their experimental results showed for semi-structured tasks such as AICS evaluation, the experience level had significant effect on audit judgments. They also showed the minimum level of experience needed for an auditor to evaluate AICS is senior rank standing.

5.3 Effects of Auditors' Rank and Risk preference

Farmer (1993) conducted an experimental study to determine if auditors' judgments in evaluating AICS reliability are influenced by their *risk attitudes*. The experience level of the subjects (auditors) in the study ranged from "senior" with two years experience to "senior manager" with 11 years experience. The auditors were classified into two categories based on their risk attitudes: risk-averse and risk-preferent. Multiattribute utility theory was employed to determine the risk attitude of auditors. Auditors in each group were interviewed and their responses in evaluating the reliability of different AICS were recorded. Analysis of the results showed no significant difference between the judgments of auditors with different risk attitudes. However, there was a significant difference between the judgments of audit seniors and audit managers in their evaluation of AICS. This indicated the effect of experience was more significant than the risk preference of auditors.

5.4 Effects of control environment, system boundary, and system internal regulators

Nanni and Abdolmohammadi (1999) studied the effects of environmental control, system boundary, and system internal regulators on the AICS reliability. *Environmental controls* are factors that affect system stability such as management philosophy and operating style, organization structure, etc. *System boundary* imposes limits on the access that external variables have to the system. Examples of system boundary include approval routines, authorization standards, etc. *System internal regulators* are techniques used to monitor and control the accounting system. Regulators are classified into two groups: (1) feedback regulators (tests or verification procedures, such as bank reconciliations) and (2) programmatic regulators (implementation of officially established standards such as segregation of duties). Experimental results showed that all variables significantly affected AICS reliability. In particular, internal regulators had the greatest effect, while the environmental factors had the least. This finding was consistent with earlier conclusion made by Nichols (1987) that of the many factors relevant to AICS evaluation only a few tend to dominate.

5.5 Effects of Qualitative Characteristics of Compliance Errors

Ferris and Tennant (1984) studied the impact of qualitative characteristics of compliance errors on the auditor's evaluation of AICS. Two qualitative characteristics were considered: (1) intentionality of error (intentional or unintentional) and (2) monetary impact of error (monetary or non monetary consequence). Results revealed that the type of compliance error affect the auditor's AICS evaluation. It was also found the auditor's decision regarding substantive testing was influenced by the error qualitative characteristics.

5.6 Effects of the Assumptions behind AICS Reliability Models

A common criticism of descriptive AICS reliability models is that they are based on some restrictive (and simplifying) assumptions about the actual accounting environment. Nevertheless, those models in many situations are robust enough to yield valid results. Kenchel (1985) investigated the results of two AICS reliability models, one of which assumed that process error rates are *independent* from each other, and the other assumed error rates were *mutually exclusive*. Independency of error rates means that the occurrence of one error type does not affect the probability of the occurrence of another error type. Mutual exclusiveness of error rates means that no more than one type of error can occur at the same time. If error rates are mutually exclusive it implies they are dependent. In his study, Kenchel compared the results of the two analytical models based on the above-mentioned assumptions with results obtained from simulation models. He concluded that both models, one based on independence of error rates and the other based on the mutual exclusiveness assumption, consistently provided close approximation of the actual reliability of the AICS. He also concluded that in cases where error rates were very high (which seldom occurs in practice) neither model produced accurate results.

6. Summary

Important progress has been made in the reliability evaluation and design of AICS since the 1970's. A notable development has been the growing use of reliability theory to improve the proposed models. We suggest reliability modeling should expand and broaden to adopt an expressly interdisciplinary approach that should include management science tools, expertise of accountants, and human elements.

This paper has presented a literature review of state-of-the-art models for evaluation of the reliability of existing and planned AICS. These models may help in designing an optimal internal control system if none exists. Table 5 presents a summary of the descriptive and prescriptive reliability models discussed in this paper along with experimental studies on factors influencing reliability estimation of AICS. The concept of structural importance for each process in an AICS was also presented to identify processes with the highest impact on the system. This could be used as a guideline for management to allocate financial resources efficiently to improve the system performance. Several numerical examples and case studies were discussed to show how the models can be used in practice.

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Table 5
AICS Modeling Classification, Focus, Strength and Weakness

Models	Group	References	What do they do? (Focus)	Strengths	Weakness
Process Reliability Estimation	*Historical Data*	Stratton (1981) and Stratton (1994)	Estimation of the reliability of each process in the AICS	Unbiased reliability estimate	Data on number of errors that occurs in each process must be available
	Auditor's Judgment	Srinidhi and Vasarhely (1989)		No need to collect data on the error occurrences in each process	Subjective estimates are affected by factors described in Section 5 of the paper
Descriptive Models	*Markov Process*	Felix and Grimlund (1977), Grimlund (1982), and Yu and Neter (1973)	Models determine the status of a document as it goes through processing	Provides information on the status of the document as it goes through processing	Need to estimate the transition probabilities May not determine optimal solution
	Models based on Control step performance	Cushing (1974), Cushing (1975), Ishikawa and Smith (1972), Ishikawa (1972), Ishikawa (1975), and Soliman (1979).	Models determine the AICS reliability given process reliabilities	Cushing's model determines the cost savings due to the use of internal controls	Need to estimate the probabilities of parameters related to control steps May not determine optimal solution
	Models Based on process Reliabilities	Bodnar(1975), Srivastava and Word (1983), Srivastava (1985), Stratton (1981), and Stratton (1994)	Models use block diagrams to determine AICS reliability in terms of the process reliabilities	Models can determine the structure importance of each process in the AICS.	Need to estimate process reliabilities May not determine optimal solution

Table 5
AICS Modeling Classification, Focus, Strength and Weakness (Continued)

Models	Group	References	What do they do? (Focus)	Strengths	Weakness
Prescriptive Models (Optimization Models)	*Optimal Allocation of Control components*	Belkaoui and Henin (1977), and Hamlen (1980)	Models allocate control components in an AICS such that system reliability is maximized subject to budgetary constraints	Elimination procedure introduced in Belkaoui and Henin (1977) reduces the number of iterations and the time needed to reach the optimal solution	Need to estimate the probabilities of parameters related to control steps
	Optimal Assignment of Tasks	Srinidhi (1988)	Model assigns audit tasks to staff such that AICS reliability is maximized	Modeler has the option of not assigning auditors to certain tasks	Method does not consider task durations as well as the auditors' time availabilities
Experimental Studies	*Segregation of duties*	Srinidhi (1994)	Study the effects of segregation of duties on AICS reliability evaluation	N/A	N/A
	Assumptions behind AICS Models	Kenchel (1985)	Study the effects of model assumptions on AICS reliability estimate		
	Auditor's Experience, Rank, and Risk Preference	Abdolmohammadi and Wright (1987), Farmer (1993), and Nanni (1984)	Study the effects of auditor's experience, background, and risk preferences on auditor's evaluation of AICS		

Table 5
AICS Modeling Classification, Focus, Strength and Weakness (Continued)

Models	Group	References	What do they do? (Focus)	Strengths	Weakness
Experimental Studies	*Control Environment and System boundary*	Nanni and Abdolmohammadi (1999)	Study the effects of control environments, system boundary and internal control regulators on AICS evaluation	N/A	N/A
	Qualitative Characteristics of Compliance Errors	Ferris and Tennant (1984)	Study the effects of errors' qualitative characteristics on AICS evaluation		

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