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ABSTRACT

This paper describes a microeconomic theory-based tool, called cost analysis, which can be used in MIS research to develop guidance for systems analysts and information resource managers. An example of this guidance is a matrix of decision making contexts versus appropriate MIS/DSS support. Systems analysts can use this matrix to help identify appropriate MIS/DSS design alternatives. Information resource managers can use this matrix to help plan for the proper evolution of MIS/DSS support.

Introduction

This paper describes an approach for determining what kind of management information systems (MIS) or decision support systems (DSS) are appropriate for various decision making contexts. This approach, called cost analysis, is useful in research developing guidance for systems analysts choosing information support for decision makers, and in research developing guidance for information resource managers planning the MIS* portfolio. One result of cost analysis is a matrix of decision making contexts versus appropriate MIS support. This matrix can be used by systems analysts to identify viable design alternatives. The matrix can also be used by information resource managers to identify and plan for appropriate changes in the firm's MIS portfolio.

Cost analysis maps appropriate MIS support to various decision contexts based upon problem complexity, and the impact of complexity upon the cost of making decisions. It is hypothesized that the cost of making decisions of a given quality increases as problem complexity increases.** Problem complexity is defined along four dimensions:

- Problem Duration—the time allowed for problem solution
- Problem Homogeneity—the lack of problem type variety
- Problem Predictability—the ability to forcast the occurrence of problems
- Problem Knowledge—the understanding of the problem; problem structure

A *decrease* in any of these dimensions represents an *increase* in problem complexity. For example, a decrease in problem knowledge in a decision context is expected to reduce the average decision quality produced. This quality can be increased to its initial level via increased investment in MIS (e.g., more sophisticated MIS) and/or in management (e.g., spending for management training or hiring more competent managers). Thus, the cost of producing decisions at the intitial quality level increases as problem complexity increases.

Alternative MIS can be compared based upon the cost of producing equal quality decison in an environment described in terms of problem complexity. If the complexity assocated with a specific context results in higher decision production costs using one MIS than that using another MIS, then the second MIS is preferred. This cost analysis approach is described in greater detail below, and applied to determining appropriate MIS support for contexts within the following descriptive frameworks:

- product life cycle
- Gorry-Scott Morton management planning and control activities

The product life cycle framework provides a vehicle for understanding the application of cost analysis to MIS portfolio planning. A profile of appropriate MIS is developed, in accord with changing decision making contexts associated with the manufacture of products progressing through their life cycles. These changing decision contexts reflect changes in marketing and manufacturing strategies. The Gorry-Scott Morton framework provides an opportunity for understanding the application of cost analysis to systems design. Categories of appropriate MIS are developed for specific management planning and control activities. These catagories can be used by systems analysts to identify appropriate MIS support of managerial activities.

Using these two frameworks as examples also allows a demonstration of support for the validity of cost analysis.

This demonstration involves a comparison of two manufacturing MIS. It is shown that many manufacturing MIS failures can be explaned by attempts to implement these systems in contexts identified as inappropriate by cost analysis.

Cost analysis is built upon microeconomic theory. Here decisions are produced instead of physical units. This production can be modeled by linking the use of certain physical resources (computer software, managers, communications devices, etc.) with decisions. As with physical production, a trasformation of raw materials occurs. The raw material of decision production is information, transformed from its initial state (data) to its final form (decisions). The output of decision production (i.e., decisions) is treated as one of many inputs to a firms's production system. For example, in the manufacture of cars, manufacturing planning and control decisions are considered a class of input along with raw materials, equipment, and non-management labor. See Cooper (1983) for a detailed discussion of decision production.

This theoretical foundation provides much of cost analysis' power. It also results in constraints due to underlying assumptions. These assumptions are thus explored through a formalization of cost analysis in terms of a microeconomic decision production model. It is found that behavioral constraints are relatively weak, providing assurance that cost analysis is applicable in a wide variety of contexts.

The paper is organized in the following manner. The next section provides details of the cost analysis approach. The following section applies cost analysis to the product life cycle and Gorry-Scott Morton frmeworks. Discussion continues with the development of a formal production model describing cost analysis. This model is used to discover implications of cost analysis assumptions. Finally, a concluding section summarizes the paper and provides direction for future research.

The Cost Analysis Approach

An MIS can be described as a "bundle" of attributes, such as response time, underlying model generality, access restrictions, etc. This section uses cost analysis to determine MIS attributes appropriate for given problem contexts. The analysis determines MIS attributes which, when combined with all other decision production inputs (e.g., staff and management labor), result in the least costly way to make decisions of a given quality. As will be illustrated, substitution among decision production inputs forms an integral part of identifying decision production costs. Efficient use of decision production inputs is assumed.

Cost analysis takes the following form:

1. MIS attributes are identified, and associated attribute pairs are determined. For example, the attribute pair: slow response—fast response is used to represent the response time attribute.

2. Context descriptors are then identified, and associated context descriptor pairs are determined. For example, the descriptor pair: long duration—short duration is used to represent the problem duration complexity context descriptor.

3. MIS attributes and context descriptors are then matched, based upon the interaction of their representing pairs. For example, slow MIS response (e.g., batch) is expected to have a different effect upon decision making than fast MIS response (e.g., on-ling) when solving problems of short duration. This differential effect results in differently shaped total cost curves representing decision production with batch MIS as opposed to decision production with on-line MIS.

4. These cost curves are then compared, and the least cost MIS attributes for the context are chosen.

Steps 1 and 2, above, are less formal in nature. Both MIS attributes and context descriptors are derived from MIS experience and MIS research. Thus, the following discussions focus upon steps 3 and 4 in more detail. For illustrative purposes, four MIS attributes are used:

- Response Time—time required for an MIS to provide requested information. The attribute pair is slow (or batch) systems versus quick (or on-line) systems

- Model Variation—variety of models used by the MIS. More available models enable the MIS to be more adaptable. The attribute pair is fixed with few model variations versus adaptable with many model variations.

- Access Restrictions—difficulty in getting use of the computer (MIS) facilities. The attribute pair is scheduled periodic access versus unscheduled ad hoc access.

- Decision Making Focus—focus of the MIS in support of decision making. This ranges from helping define or structure problems to actually making the decisions. An important distinction between "decision structuring" and "decision making" MIS is in terms of the restrictiveness of their assumptions. Decision structuring MIS includes less restrictive assumptions; the underlying MIS model contains much less problem-specific information concerning applicable variables, causal links, etc. The attribute pair for decision making focus is thus decision structuring versus decision making.

In addition, the four problem complexity dimensions described earlier are employed as context descriptors. Brief definitions for these descriptors are repeated below, along with their context descriptor pairs:

- Problem Duration—time allowed for problem solution. The descriptor pair is long versus short duration.
- Problem Homogeneity—lack of problem type variety. The descriptor pair is few versus many problem types.
- Problem Predictability—ability to forcast the occurrence of problems. The descriptor pair is predictable versus unpredictable.
- Problem Knowledge—understanding of the problem; problem structure. The descriptor pair is much versus little knowledge.

Using these MIS attributes and context descriptors as examples,the details of Step 3 are discussed next.

Step 3 of Cost Analyses

The existence of interactions between MIS attributes and problem complexity dimensions are illustrated in Figure 1 and described below. The cost curve implications of these interactions are included in the following descriptions, and illustrated in Figure 2. Before focusing upon individual cost curves, two assumptions concerning the general cost curve shape must be addressed:

A. The cost of making a given level of decision quality is a nondecreasing function of any problem complexity dimension, ceteris paribus. This follows from the notion that decisions are harder to make in more complex environments.

B. For a given level of decision quality, the least cost combination of decision production resources in a simple problem context tends to cost more than at least one other combination of decision production resources in a complex problem context, ceteris paribus. This follows from the notion of specialization: decision production developed for a specific environment is more efficient in that environment than other decision production systems.

Cost curves representing each MIS attribute—problem complexity dimension interaction are described next. Interaction associated with the problem duration complexity dimension is presented first in more detailed manner. This is done to help give a better understanding of assumption A and B.

Problem Duration complexity refers to added decision making complexity due to the reduction in time allowed to make a decision; i.e., the reduction in decision solution lead time. It is expected that as this lead time gets shorter and shorter, it becomes harder and harder to make good (equal) quality decisions. As solution lead time shortens, in order to reproduce equal quality decisions more resources must be utilized per decision. For example, more staff personnel must be assigned, information must be purchased from external sources, etc. These additional resources result in increased total decision production costs, assuming a constant number of decisions. Thus, Figure 2A indicated the upward sloping cost curves associated withe assumption A. Figure 2A also depicts different cost curve responses to two different decision production systems. Both systems differ in MIS support: slow response MIS (e.g., batch) versus quick response MIS (e.g., on-line). In addition, both systems differ in non-MIS related resources such that each system results in the most efficient production of the same decision quality for every level of problem duration complexity, given the MIS constraint. With long duration problems, total decision production costs associated with the fast response MIS are expected to be higher than that for the slow response MIS. This expectation is due to the greater expense of on-line MIS, and the fact that the batch MIS will work just as well with long lead time problems. However, as problem solution lead time becomes shorter, after some point, the batch MIS looses its decision producing value at a greater rate than the on-line MIS. Thus, other resources (staff, management, outside information sources, etc.) must be used at a greater rate for the batch MIS system that for the on-line MIS system in order to keep the same decision quality level. This differential effect of problem duration upon batch versus on-line MIS based decison production implies the crossing of total cost curves, as depicted in Figure 2A, and as stated in assumption B.

Problem Homogeneity refers to the variety of problems encountered. In environments where few different kinds of problems are encountered, a fixed MIS with few model variations will be as effective in decision production as more adaptable MIS with many model variations. The more adaptable MIS, however, will typically cost more to develop, maintain, and operate. In environments where many different kinds of problems are encountered more management and staff labor is required to overcome the fixed MIS deficiencies; this extra labor is not required for the more adaptable MIS. Thus, under the more complex condition of large problem variety, deci-

MIS Attributes	Problem Duration	Problem Homogeneity	Problem Predictability	Problem Knowledge
	------------Problem Complexity Dimensions------------			
Response Time	X*			
Model Variations		X		
Access Restrictions			X	
Decision Making Focus				X

Figure 1

MIS Attribute—Problem Complexity Interaction

*X indicates that the problem complexity dimension differentially affects the MIS attribute pair.

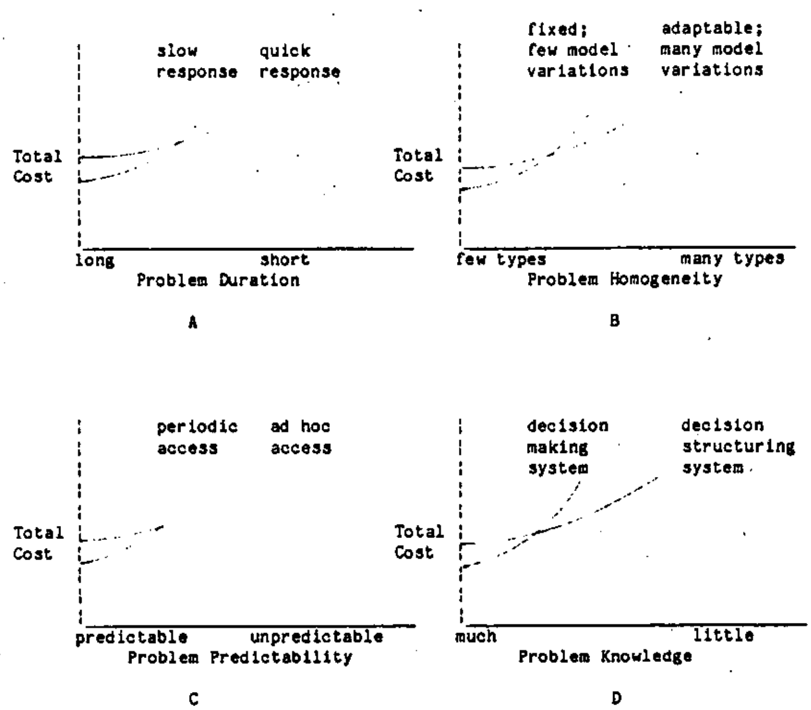

Figure 2

Cost Curve Interaction Between MIS Attributes and Problem Complexity Dimensions sion production using the more adaptable MIS is expected to be less costly than that using the fixed MIS. This implies the cost curve relationships illustrated in Figure 2B.

Problem Predictability refers to the ability of decision makers to predict problem occurrence, and thus schedule decision production activities. With very predictable problems (e.g., budget reviews), MIS activities can be periodically scheduled, enabling more efficient use of computer resources. Allowing ad hoc access requires "excess" computer capacity, resulting in higher costs in predictable problem occurrence contexts. However, as problem occurrence becomes less predictable, decision production systems restricted to periodically scheduled MIS must add other resources at a rate higher than decision production systems allowed ad hoc MIS access. This results in the cost curve form illustrated in Figure 2C.

Problem Knowledge refers to how well the problem is understood; i.e., the problem structure. With very structured problems, decisions can almost be automated. Decision production cost is thus associated with a "decision making" MIS, and little management labor. Decision structuring, MIS (e.g., those which help define the problems) are of little value with structured problems, for structured problems are well-defined. Decisions produced using decision structuring MIS in structured contexts are thus done essentially by management and staff labor. In a structured context, decision production costs associated with a decision making MIS are expected to be less than that associated with a decision structuring MIS. As problems become less structured, a decision making MIS has less and less value, until it is essentially useless, and substituted by management and staff labor. In less structured contexts, decision structuring MIS becomes useful, and less management/staff labor is required to make a given decision quality as compared to that required when using a decision making MIS. Figure 2D illustrates the cost curve implication of this discussion.

Step 4 Cost Analysis

Above discussions provide the relative cost of using MIS with specific attributes in decision making contexts described by problem complexity dimensions. Step 4 of cost analysis is a two-phase process. First, a matrix of appropriate MIS support based upon Step 3 cost curves is developed. This is illustrated in Figure 3. Figure 3 shows, for example, that a decision making context described as having many different types of problems (Problem Homogeniety = many), each of which is typically short in duration (Problem Duration = short) is best supportd by an MIS which has quick (e.g., on-line) response and is adaptable, having many model variations. The second phase of Step 4 is an application of this matrix to actual decision making contexts. This second phase is described next for manufacturing contexts and for general management planning and control contexts.

Applying Cost Analysis to Two Example Frameworks

This section illustrates the use of cost analysis to facilitate MIS portfolio planning and MIS systems design. The MIS portfolio planning example focuses upon a product life cycle framework which describes changes in a firm's marketing and manufacturing strategies as its products evolve. Cost analysis enables a profile of MIS support to be identified which matches manufacturing management's requirements throughout this evolution. MIS portfolio planners can use this profile to define future MIS requirements. The MIS systems design example is based upon Gorry and Scott Morton's management planning and control activities framework. Cost analysis enables appropriate MIS for various management activities to be determined. This can be used by systems analysts to help identify design alternatives when building systems for managerial support.

In addition to these examples, this section examines problems associated with the implementation of a manufacturing MIS. This discussion provides an empirical example of the cost analysis concepts, adding support to the validity of this approach.

MIS Attributes and the Product Life Cycle

Haynes and Wheelwright (1979) describe typical manufacturing environments associated with the product life cycle. The product life cycle is divided into four stages, ranging from low volume, low standardization, one of a kind products to high volume, high stadardization, commodity products. These manufacturing context descriptions are presented below, and then described in terms of the problem complexity dimensions. With each product life cycle stage defined by problem complexity dimensions, the matrix in Figure 3 is used to identify appropriate MIS Support.

Stage 1 products reflect custom design, and are produced in low volume. The typical manufacturing structure is jumbled flow (job shop), where manufacturing management focuses upon:

MIS Attributes		Problem Complexity Dimensions							
		Problem Duration		Problem Homogeneity		Problem Predictability		Problem Knowledge	
		long	short	few	many	predictable	unpredictable	much	little
Response Time	slow	X							
	quick		X						
Model Variations	few			X					
	many				X				
Access Restrictions	periodic					X			
	ad hoc						X		
Decision Making Focus	decision making							X	
	decision structuring								X

Figure 3

Appropriate MIS Support Matrix

- fast reaction
- estimating plant loading, costs, and delivery times
- breaking bottlenecks, order tracing, expediting

Stage 2 and 3 products move from custom design with an emphasis on quality and service, to more standardized design with fewer products, higher product volume, and finished goods inventories. The typical manufacturing structure evolves from a disconnected line flow (batch) to a connected line flow (assembly line). Manufacturing management focuses upon:

- systematizing diverse elements
- developing standards and methods improvement
- balancing process stages
- managing large specialized, and complex operations

Stage 4 products are high volume, standardized, and emphasize low cost production. The typical manufacturing structure is a vertically integrated continuous flow with long runs, specialized equipment, and standardized material. Manufacturing management focuses upon:

- meeting material requirements
- running equipment at peak efficiency
- timing expansion and technological change

These context descriptions can be related to the four problem complexity dimensions described earlier. Manufacturing management problems of stage 1 products tend to be more complex than those of stage 4. As opposed to stage 4, in stage 1:

- problem duration is shorter: fast reaction to external (custom design requirements) and to internal, (job shop production bottlenecks, expediting, etc.) demands is required;
- problems are less homogeneous: each product is different (custom designed) and requires new specifications, materials, routings, etc;
- problem occurrence is less predictable: custom products and a jumbled job shop flow result in

unpredictable effects and to unpredictable manufacturing decisions.

- problem knowledge is less: with custom products requiring new materials, processes, etc., an understanding of production lead times, costs, scrap, etc. is much less than with standardized, high volume production.

This general tendency of manufacturing management problem complexity increasing from stage 4 products to stage 1 products is illustrated in Figure 4. Though not described in detail above, product stages 2 and 3 represent appropriate intermediate levels of problem complexity, allowing a downward slope of the problem complexity curve.

Based upon the matrix in Figure 3, the final cost analysis mapping occurs in Figure 5. Here, appropriate MIS attributes based upon the problem complexity of each product life cycle stage are presented. Firms producing low volume, low standardization, custom design products (stage 1) should have MIS characterized as: quick response, adaptable/many model variations, ad hoc access, and a decision structuring focus. These attributes are commonly categorized as decision support systems. Firms producing high volume, high standardization, commodity products (stage 4) should have MIS characterized as: slow response, fixed/few model variations, periodic access, and a more decision making focus. These attributes are commonly categorized as traditional batch-oriented MIS, with daily/weekly/monthly reporting.

Interestingly, manufacturing decision support systems (DSS) are more appropriate during the initial product life cycle stages (typically early in a firm's lifetime). However, Nolan's work (1979) indicates that DSS are typically not available until much later, due to the time it takes for firms to understand an control computer technology. There is, thus, benefit in developing strategies to facilitate the early assimilation of computer based information systems in young manufacturing firms. For, this will allow the successful implementation of manufacturing management DSS early on. In addition, firms, evolving stage 1 to stage 4 products should actively review their manufacturing MIS/DSS applications portfolio to assure that it evolves appropriately.

MIS Attributes and the Gorry-Scott Morton Framework

The Gorry-Scott Morton management planning and control framework (1971) combined Simon's (1960) notion of problem programability (or structuredness) with Anthony's (1965) notion of management planning and control levels. This framework is illustrated in Figure 6, providing example management planning and control activities for each matrix cell. This section maps characteristics of these cells into the four problem complexity dimensions. From this mapping, and the cost analysis described previously, appropriate MIS support is determined for various problem structure and management planning and control levels.

Based upon Anthony's (1965) management level descriptions, Figure 6 depicts three problem complexity dimensions along the horizontal (management level) axis. These dimensions, and the placement of their associated MIS attribute pairs, are described below:

- Problem duration complexity increases from strategic planning to operational control; required problem solution response time is typically less for operational control than management control, and less for management control than strategic planning. Prior cost curve analysis indicates that fast response MIS is thus appropriate for operational control and slow response MIS is appropriate for strategic planning.

- Problem homogeneity complexity increases from operational control to strategic planning; operational control problems tend to be similar and repetitive, while strategic planning problems are typically irregular and different. Prior cost curve analysis indicates that fixed MIS with few model variations is appropriate for operational control; more flexible, adaptable MIS with many model variations is appropriate for strategic planning.

- Problem predictability complexity increases from management control to strategic planning; management control problems typically come in a rhythmic patterm (weekly, monthly, etc.), and strategic planning problems occur in an infrequent, irregular, unpredictable fashion. Operational control problems tend to appear on an ad hoc, very frequent basis. Prior cost curve analysis indicates that ad hoc MIS access should be allowed for strategic planning with periodic access for management control. Ad hoc/continuous access seems to be appropriate for operational control.

Simon's notion of problem structure provides a vehicle for the fourth complexity dimension: problem knowledge. This complexity dimension, illustrated along the vertical axis in Figure 6, depicts increasing problem knowledge complexity from structured to unstructured problems; as problems become less structured, understanding of the problem and its context diminishes. Prior cost curve analysis indicates that decision making MIS

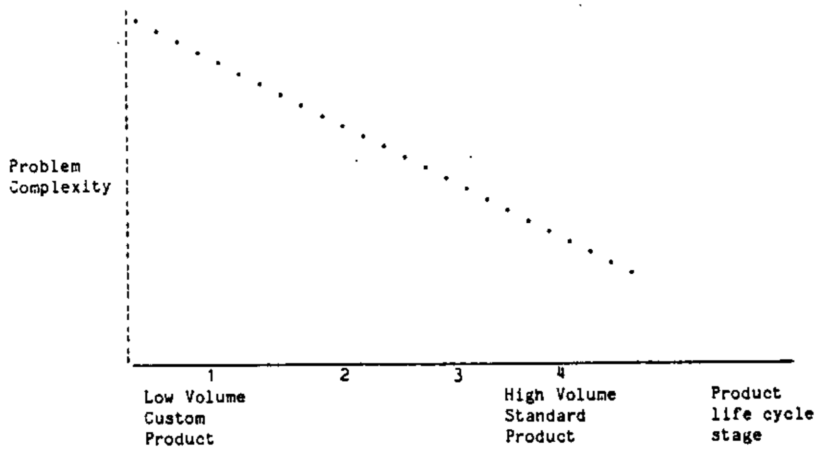

Figure 4

Manufacturing Management Problem Complexity
Versus Product Life Cycle Stage

MIS Attributes	Low Volume Custom Product 1	2	3	High Volume Standard Product 4	Product life cycle stage
Response Time	Quick			Slow	
Model Variations	Adaptable/Many			Fixed/Few	
Access Restrictions	Ad hoc			Periodic/Scheduled	
Decision Making Focus	Decision structuring			Decision making	

Figure 5

MIS Attributes Versus Product Life Cycle Stage

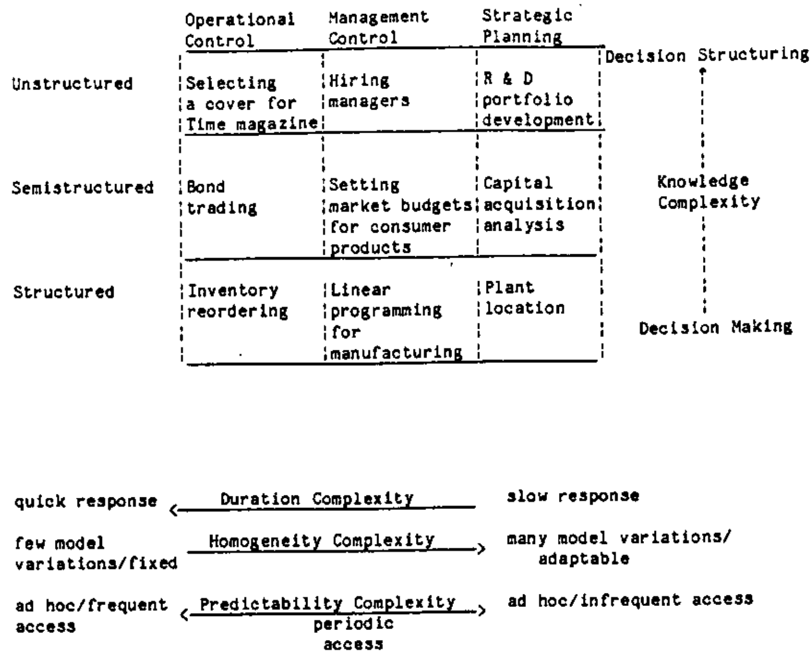

Figure 6

Gorry-Scott Morton Framework with Complexity Dimensions and MIS Attributes

are more appropriate for structured problems, and decision structuring MIS are more appropriate for unstructured problems.

Figure 6, then, illustrates appropriate MIS attributes for any of the three management activity levels in any of the three problem structure categories. For example, MIS attributes for structured operational control problems should be decision making, quick response (on-line), with few model variations, allowing ad hoc/frequent access. This mapping of appropriate MIS attributes to Gorry-Scott Morton framework can also be used to provide more general conclusions regarding appropriate MIS support.* These conclusions are introduced briefly here, and described in detail next:

- Based upon MIS response time (slow versus quick) and decision making focus (decision structuring versus decision making), conclusions concerning on-line versus batch MIS support are made.
- Combining the assumption restrictiveness aspect of decision making focus with required model adaptability, conclusions concerning the appropriate specificity of MIS models are drawn.
- Based upon MIS response time, MIS access restrictions, and the MIS model specificity conclusions, above, conclusions concerning the support function which the MIS should perform are determined.

The appropriateness of on-line versus batch MIS is depicted in Figure 7A. Batch is appropriate for more structured, strategic planning-oriented problems. Two forces lead to this conclusion. First, strategic planning is associated with slow response MIS. Second, as problems become less structured, there is an increased need for decision structuring MIS. Since the typical mode for providing MIS stucturing support is via some type of computer-human dialogue, on-line interaction becomes more important in less structured situations, and less important in more structured situations. This implies, for example, that the MIS intermediary, or chauffeur (e.g., Keen 1976) is appropriate for more structured strategic planning problems.

The level of MIS model specificity is depicted in Figure 7B. Problem Specificiy is defined here in terms of MIS model adaptability and MIS model assuption restrictiveness. MIS models, which are less adaptive and contain more restrictive assumptions, are more appropriate for a

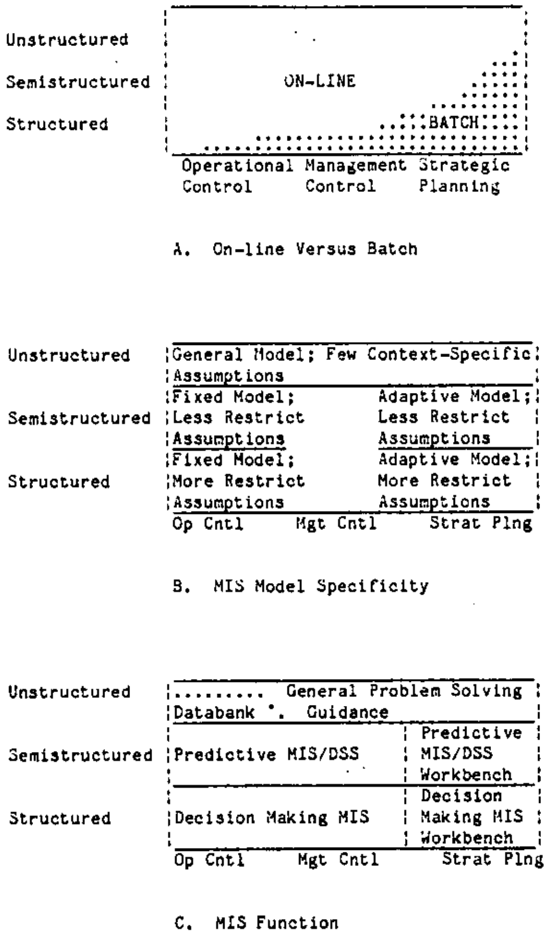

Figure 7

Implications of MIS Attributes for MIS Support

specific problem type. Thus, implications of Figure 6 concerning MIS model adaptiveness and assumption restrictiveness are used below to document MIS model specificity. The results of this discussion are used in support of subsequent discussions.

For operational control problems, MIS with few fixed underlying models are appropriate; this is due to the relative homogeneity of these problems. As problems move through management control to strategic planning, they are no longer repetitive, and become one-of-a-kind. MIS support for strategic planning problems must thus be flexible, and adapt to this problem diversity. In addition, for each management level, the restrictiveness of assumptions associated with MIS models should decrease with less problem structure. As knowledge of the problem and its context decreases, MIS models must contain less restrictive assumptions/information concerning causal relationships, appropriate varibles, and decision maker preferences. That is, MIS must move from decision making to decision structuring. Finally, as illustrated by the top row of Figure 7B, unstructured problems for any management level are, by definition, so ill-understood that only very general notions of causality, relevant variables, and/or preferences can be employed.

MIS function refers to the decision making/supporting tasks which are appropriate for an MIS to perform. As illustrated in Figure 7C, MIS functions are depicted here largely in terms of Mason's (1981) MIS topology. Briefly, Mason's hierarchic typology begins with a databank, consisting of a data base and a query facility. This type of MIS is merely a "fact generator;" any meaning associated with the facts must be developed by the decision maker. Next is a predictive system, which adds the ability to make predictions and inferences based upon databank facts and causal models. The third type is a decision making system. While a predictive system can only answer "what if" questions, a decision making system incorporates the decision maker's preferences, allowing it to choose among alternatives, and present the decision maker with the optimal (or satisficing) alternative. (Note that this MIS topology is in accord with Alter's-1977.)

Movement up Mason's hierarchic MIS topology implies greater problem understanding. This is analogous to the requirements associated with MIS decision focus, going from decision structuring to decision making. Mapping of Mason's typology to the decision focus continuum is depicted in Figure 7C, for operational control problems and management control problems. Note that the usefulness of any type of problem-specific MIS (e.g., databank) diminishes for very unstructured problems. This is due to the decrease in problem knowledge: if little or nothing is known about the problem, appropriate data cannot be gathered; thus only general problem solving guidance can be offered. This guidance can take the form of creativity "meta-hints" (Ishiketa, et al. 1977), automated tree structuring (e.g., Decision Support Software, Inc.'s Expert Choice), etc. The usefulness of problem-specific MIS also diminishes for problems which are more managerial control or strategic planning in nature. These problems exhibit much less homogeneity; the types of future problems are not known a priori. Thus, data are more difficult to gather in support of future problems.

Structured and semistructured strategic planning problems represent a special case of Mason's typology. The large variety of problems associated with strategic planning would require very adaptable decision making and predictive MIS. However, additional MIS attributes associated with these problems are slow required response time and infrequent access. This allows for the creation of an MIS which is tailor-made for each problem. That is, rather than develop and maintain a large set of adaptable MIS to cover potential strategic problems, it can be more cost-effective to develop a MIS creation workbench, which facilitates the building of problem-specific decision making and predictive MIS.

Implications for MIS support described above do not conflict with prior conclusions drawn from the Gorry-Scott Morton framework (e.g., Keen and Scott Morton 1978, p. 92-93). Rather, they are in accord with, and extend prior research in the area of MIS/DSS planning, design, and implementation. In addition, this section's discussions provide theory-based support for the framework's use and conclusions drawn therefrom.

MRP Versus ROP Management Information Systems

In the production and inventory management context, problems concerning the quantity and timing of material/component/assembly purchase and manufacture are typically solved by middle management and staff using either material requirements planning (MRP) or reorder point (ROP) based information systems. As described in Cooper (1985), many attempts at replacing ROP systems with MRO systems have failed. This section uses cost analysis to gain insight into these failures. It is hypothesized that one reason for the lack of MRP success is an attempt to implement MRP in contexts deemed inappropriate by cost analysis. This hypothesis is supported by a survey depicting MRP success rates by decision making context.

The attributes of MRP and ROP systems are very similar. Response time is typically daily or weekly, model variations are few and fixed, access is typically periodic (e.g., weekly) and scheduled, and the decision making focus tends toward decision making rather than decision structuring. This characterization typifies MIS appropriate for relatively simple contexts; for example, firms producing Stage 4 (high volume, standard) products. (see Figure 5.)

One MIS attribute on which MRP differs form ROP to the greatest degree is decision making focus. Though both MRP and ROP are more decision making than decision structuring, the MRP model is much more restrictive; it contains many more assumptions/information describing causal relaitonships, appropriate variables, and decision maker preferences. In fact, many of the ROP assumptions are contained within the MRP model. For example, many MRP lot-sizing algorithms involve the economic order quantity approach. Thus, as illustrated in Figure 7B, the ROP model tends to be more appropriate in less structured contexts (where problem knowledge is less), and MRP tends to be more appropriate in more structured contexts (where problem knowledge is greater).

Referring back to the Haynes and Wheelwright product life cycle discussion above, problem knowledge is highest for Stage 4 (high volume, standard) products and lowest for Stage 1 (low volume, custom design) products. Based upon cost analysis, successful MRP use would thus be expected in the manufacture of Stage 4 products, while less MRP success would be expected for Stage 1 products. This is counter to traditional advice for MRP implementation (e.g., Wight 1974 and Orlicky 1975). A study by Cooper (1985) provides evidence that this is indeed the case. A logit model based upon random survey data from 62 manufacturing firms across the United States resulted in the following probabilities of successful MRP use: for Stage 4 manufacturing—83%, for stage 1 product manufacturing—48%.

Based upon cost analysis, many MRP failures can thus be identified as attempts to implement these MIS in inappropriate contexts. Support of this conclusion by the survey data provides evidence for the validity of cost analysis.

Conclusion

Discussions above have applied the cost analysis approach to MIS portfolio planning and system design problems. An ability to describe various contexts in terms of problem complexity, and translate the complexity descriptions, via cost analysis, into appropriate MIS support was demonstrated for the firm's product life cycle and the Gorry-Scott Morton management planning and control activities frameworks. In addition, support for the validity of the cost analysis approach was provided by an explanation of the many MRP implementation failures.

The next section formalizes cost curve analysis. Decision production functions are developed which characterize the relationships described thus far. This formalization provides a better understanding of the cost curve approach's strengths and weaknesses.

Cost Curve Approach Formalization

Cost analysis is based upn the notion that decision making can be viewed in much the same manner as the production of goods and services. For example, some combination MIS and management inputs produce decisions in a manner analogous to the way machines and labor produce, say, cars. Given this view, microeconomic theory is used to guide the shape and interpretation of decision making cost curves. Since cost analysis is guided by microeconomic theory, if microeconomic assumptions prove to be too restrictive or unreasonable, cost analysis loses its attractiveness as a tool. To this end, decision production is formalized here as a general two-factor model with constant factor costs. Important microeconomic assumptions are then examined, and behavior implied by these assumptions is evaluated. The production model is described first.

The following decision production function is proposed:

$$Q = F(K,L,X)$$

where

Q: Decision Quality

F: Function with continuous first and second derivatives

K: Capital (MIS) input

L: Labor (management and staff) input

X: Problem complexity factor

The following are also assumed:

. $K, L, X, > 0$

. $F_L, F_K, > 0$*

. $F_X, F_{LL}, F_{KK} < 0$

This decision production function is a typical two factor production model with the addition of a problem complexity factor (X). This complexity factor has a negative influence on production ($F^X < 0$).

Assuming constant average costs for MIS and management/staff input, the following total cost function is proposed:

$$C = wL + rK$$

resulting in the following cost minimizing Lagrangean:

$$Z = wL + rK + M(Q - F)$$

Where C is total decision production cost, w and r are average cost for MIS and management/staff input, respectively, and M is the marginal cost of producing Q.

Cost minimization is relatively weak behavioral constraint. Thus, the first task of this section is to demonstrate that assumption A can be characterized in terms of cost minimizing behavior.* That is, cost minimization is a sufficient condition which results in:

$$(1) \quad \frac{\delta C}{\delta X} = w\frac{\delta L}{\delta X} + r\frac{\delta K}{\delta X} >= 0$$

From first-order conditions:

$$(2) \quad \frac{\delta L}{\delta X} = \frac{1}{|H|}[-F_X(F_L M F_{KK} - F_K M F_{LK}) - F_K(-F_L M F_{KX} + F_K M F_{LX})]$$

$$(3) \quad \frac{\delta K}{\delta X} = \frac{1}{|H|}[F_L(-F_L M F_{KX} + F_K M F_{LX}) + F_X(F_L M F_{KL} - F_K M F_{LL})]$$

In addition, since the first-order conditions require that:

$$(4) \quad M = \frac{w}{F_L} = \frac{r}{F_K}$$

then equations (2), (3), and (4) can be substituted in equation (1) and simplified to result in:

$$(5) \quad \frac{\delta C}{\delta X} = \frac{-F_X}{|H|}(w^2 F_{KK} - 2\,wrF_{KL} + r^2 F_{LL}) = -F_X M > 0$$

Since $F_X < 0$ and $M > 0$, cost minimizing behavior more than fulfills the individual cost curve shape requirements.

The second task of this section is to indicate what production behavior is implied by assumption B.* First, identify the cost of producing decisions using the decision production technology which is most efficient in low complexity contexts as C_{low}. Similarly, identify the cost of producing decisions using the decision production technology which is most efficient in high complexity contexts as C_{high}. Then, given the C_{low} is less than C_{high} initially, assumption B states that after some complexity level, C^{low} will be more than C^{high}. For this to occur, for a reasonably large domain, it is sufficient that after some complexity level:

$$\frac{\delta^2 C_{low}}{\delta X^2} > \frac{\delta^2 C_{high}}{\delta X^2}$$

From (5), this means that after some level of X:

$$(6) \quad -[F_{XX}M + F_X(\delta M/\delta X)]_{low} > -[F_{XX}M + F_X(\delta M/\delta X)]_{high}$$

or, substituting from (4).

$$-[F_{XX}(\frac{w}{F_L}) + F_X(\frac{-wF_{LX}}{F_L^2})]_{low} > -[F_{XX}(\frac{w}{F_L}) + F_X(\frac{-wF_{LX}}{F_L^2})]_{high} >$$

Since F_x is negative, if F_{LX} (and thus F_{KX}) is assumed negative, then (6) holds if increasing complexity has a stronger negative influence upon low complexity decision production technology than upon high complexity decision production technology.* The additional assumption (F_{LX}, $F_{XX} < 0$) makes intuitive sense, in that increasing complexity negatively influences the productivity of individual inputs, as well as the production function in general ($F_x < 0$).

The conclusions above are based upon a production model where input costs and decison quality are assumed constant. There are certain contextual descriptions (such as Anthony's management levels) which conflict with these assumptions. As described below, these conflicts do not necessarily diminish the applicability of cost analysis.

For contexts where changes in decision volume occur in addition to changes in problem complexity some confounding may result.** For example, if volume decreases with problem complexity, total cost curves as complexity increases may be downward, rather than upward sloping. This in itself does not nullify the cost analysis technique. As long as the low complexity decision production technology costs intersect high complexity decision production technology costs from below, all conclusions described earlier still hold. Confounding may occur, however, if these cost curves do not intersect, or intersect multiple times. The problem is to determine whether

$$\frac{\delta^2 C_{low}}{\delta X^2} > \frac{\delta^2 C_{high}}{\delta X^2}$$

is reasonable to expect when decision volume changes with problem complexity. This issue is addressed next.

Instead of (5), substitute:

$$\delta C/\delta X = -F_X M + M\, \delta Q/\delta X$$

This results in:

$$\delta^2 C/\delta X^2 = -F_{XX} M - F_X(\delta M/\delta X) + M \frac{\delta^2 Q}{\delta X^2} + \frac{\delta M}{\delta X}\, \delta Q/\delta X$$

The intersection requirement then becomes:

$$[-F_{XX} M - F_X(\delta M/\delta X) + M \frac{\delta^2 Q}{\delta X^2} + \frac{\delta M}{\delta X} \frac{\delta Q}{\delta X}]_{low} > [\ o\ ]_{high}$$

or, substituting from (4),

$$(7)\quad [-F_{XX}(\frac{w}{F_L}) - F_X(\frac{-wF_{LX}}{F_L^2}) + \frac{w}{F_L} \frac{\delta^2 Q}{\delta X^2} + (\frac{-wF_{LX}}{F_L^2}) \frac{\delta Q}{\delta X}]_{low} > [\ o\ ]_{high}$$

By assumption, $\frac{\delta^2 Q}{\delta X^2}$ and $\delta Q/\delta X$ are the same for both decision production technologies. Thus, in addition to the explanation associated with (6), assuming $\frac{\delta^2 Q}{\delta X^2}$ is not significant:

- If $\delta Q/\delta X >= 0$, then no confounding occurs
- If $\delta Q/\delta X < 0$, then confounding may occur if, for example, the reduction of Q as complexity increases is significantly larger than the negative effect of complexity upon the production of Q

Discussions based upon Anthony's management level descriptions are affected by changes in decision volume; the number of decisions per time period are expected to decrease from operational control to strategic planning. Since homogeneity complexity increases from operational control to strategic planning, some confounding may occur. Thus, for example, arguments surrounding MIS/DSS workbenches are weakened.

Some contexts may exhibit changes in input prices along with changes in complexity. For example, along Anthony's management level continuum, wages associated with management labor are expected to be more for strategic planning than operational control. Analogous to the above discussions, questions concerning confounding due to variable wage rates can be answered based upon the reasonableness of:

$$(8)\quad [-F_{XX} \frac{w}{F_L} - F_X(\frac{-wF_{LX}}{F_L^2}) + L\, \delta w/\delta X]_{low} > [\ o\ ]_{high}$$

By assumption, $\delta w/\delta X$ is the same for both decision production technologies. Thus, in addition to the explanation associated with (6),

- If $\delta w/\delta X >= 0$, then no confounding occurs
- If $\delta w/\delta X < 0$, then confounding may occur if labor used by the low technology production is significantly larger than that used by high technology production such that the negative effects of complexity are surpassed.

Discussions based upon Anthony's management level descriptions are affected by changes in labor wages. This effect is opposite that of decision volume changes; wages are expected to increase from operational control to strategic planning. The effects of changes in decision volume and labor wages are summarized in Figure 8. As illustrated, earlier discussions surrounding Anthony's management level descriptions fall into either the southwest or northeast quadrant, and are thus slighly confounded.

Thus far, problem complexity has been treated as a single variable. To include the effect of four complexity dimensions, add the following function to the above formulation:

$$X = G(x^1, x^2, x^3, x^4)$$

Where $x^1 - x^4$ are problem complexity dimensions, and G is a continuously differentiable function, such that $G^x > 0$. Any increase in one complexity dimension increases problem complexity. This is compatible with the demonstrations above.

Above discussions have demonstrated that the two basic assumtions underlying cost analysis can be characterized by cost minimizing behavior, and a decision production technology in which simple problem technology is affected more by increased problem complexity than problem technology.

These decision production behaviors form relatively weak and intuitively appealing constraints, and thus do not diminish the attractiveness of cost analysis as a tool.

Conclusion

This paper has developed a microeconomic production theoretic approach to determining appropriate MIS support for decision making. This approach analyzes the cost of producing decisions based upon the amount of context complexity. An MIS which provides the least cost production of a given decision quality in a specific context is the MIS appropriate for that context. In this manner, appropriate MIS were determined for the product life cycle and Gorry-Scott Morton frameworks. These examples illustrated the usefulness of cost analysis for MIS portfolio planning and systems design, respectively. In addition, it was also found that assumptions underlying cost analysis were reasonable and relatively unrestrictive. This allows the approach to be used in many different contexts.

The purpose of this paper is to offer a tool which can be used in research to develop guidance for systems analysts engaged in systems design, and in research to develop guidance for information resource managers planning information system development. Support for the validity of cost analysis is offered in terms of its theoretical grounding and in the empirical example of MRP success. In addition, this validity is supported by cost analysis' ability to consider factors stressed as important in MIS research. For example, Mason and Mitroff (1973) indicate that important MIS research variables consist of the decision maker's psychological type, the problem type, MIS attributes (method of evidence generation, guarantor of evidence, and modes of presentation) and organizational context. This paper focused upon MIS attributes, problem type, and organizational context. In addition, as described below, cost analysis is robust enough to include the consideration of decision maker attributes such as psychological type.

Further research into cost analysis can take two forms. First, the corrent approach of mapping from contexts via problem complexity to MIS attributes can be enhanced, identifying new mappings. For example, consider describing a context in terms of whether it is predominately cooperative or competitive. This degree of cooperation can be mapped into a new problem complexity dimension called problem noxiousness, which represents the effect of environmental factors actively working against the production of quality decisions. MIS attributes which may be differentially affected may include the degree of data processing centralization. The total cost curves may look like that in Figure 9. Here, technical economies of scale and shared data associated with centralized data processing allow less expensive decision production in a cooperative environment than that with decentralized data processing. However, as the organizational units and personnel become more competitive (problem noxiousness increases) costs associated with data integrity and security, job priorities, etc. may outweigh centralization's initial advantage, leading to relatively low cost decision production with decentralized data processing.

The second form of cost analysis research involves identifying functional varibles other than problem complexity. For example, decision production "input discord" may be used to represent the mismatch between different types of inputs. An example of this variable might be a degree of mismatch between the MIS (level of aggregation, level of sophistication, etc.) and the MIS user (cognitive style, intelligence, etc.). One would expect that as input discord increases decision production decreases. The new function would thus be:

$$Q = F(K, L, X, Y)$$

where Y represents input discord, and $F_Y < 0$. Note that with the addition of input discord, all categories of important variables mentioned by Mason and Mitroff can be included in cost analysis.

The result of this research is a matrix of contexts versus appropriate MIS. Based upon primitive decision production function affecting variables such as problem complexity and input discord, decision making contexts can be defined, and appropriate MIS identified. This matrix can then be used to provide appropriate design alternatives for systems analysts, and to provide appropriate MIS portfolio for information resource managers planning the future of a firm's information system.

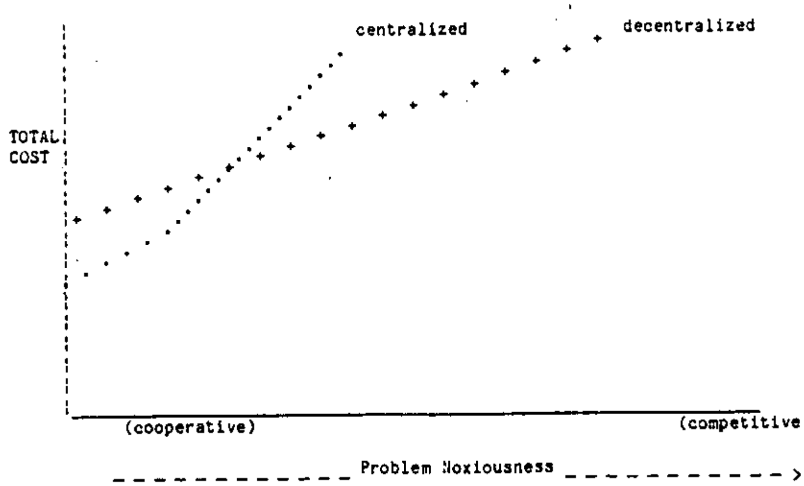

Figure 8

Confounding of Discussions Due to Changes in Decision Quality (Volume) and/or Input Price (Labor Wages) Associated with Changes in Complexity

		$\partial W/\partial X$ >=0	$\partial W/\partial X$ < 0
$\partial Q/\partial X$	>=0	No Confounding	Slight Confounding
$\partial Q/\partial X$	< 0	Slight Confounding	Maximum Confounding

Figure 9

Cooperative Versus Competitive Context, Problem Noxiousness, and Degree of Data Processing Centralization

REFERENCES

Alter, Steven L. A taxonomy of decision support systems. *Sloan Management Review,* 19,1 (Fall 1977), pp.

Anthony, R.N. *Planning and Control Systems: A Framework for Analysis.* Cambridge, Mass: Harvard University Graduate School of Business Administration, Studies in Management Control, 1965.

Cooper, R.B. A model of mrp use. 1985.

Cooper, R.B. Decision production: a step toward a theory of managerial information requirements. *Proceedings of the Fourth International Conference on Information systems,* Houston, 1983, pp. 251-268.

Gorry, G.A. and Scott Morton, M.S. A framework for management information systems. *Sloan Management Review,* 13,1 (Fall 1971), pp. 55-70.

Hayes, Robert H. and Wheelwright, Steven C. Link manufacturing process and product lifecycles. *Harvard Business Review,* January-February 1979, pp. 133-140.

Ishiketa, T.; Yokoyama, T.; Mandai, S.; Takeshima, N. A managerial decision-making tool computer-assisted problem-solving system (capss). *IFIP* 1977, pp. 85-90.

Keen, Peter G.W. Interactive computer systems for managers: a modest proposal. *Sloan Management Review,* 18 (Fall 1976), p 1-17.

Lerch, Javier F. and Mantei, Marilyn M. A framework for computer support in managerial decision making. *Proceedings of the Fifth International Conference on Information Systems,* Tucson, Arizona, November 1984, pp. 85-90.

Mason, Richard O. Basic concepts for designing management information systems. in Mason and Swanson (eds.) *Measurement for Management Decision.* Addison-Wesley, Reading, Massachusetts, 1981.

Mason, Richard O. and Mitroff, Ian I. A program for research on managemnt information systems. *Management Science,* 19, 5 (January 1973), pp. 457-487.

Nolan, Richard L. Managing the crisis in data processing. *Harvard Business Review,* March-April 1979, pp.

Orlicky, Joseph *Material Requirements Planning,* McGraw-Hill, New York, 1975.

Simon, H.A. *The New Science of Management Decision.* New York, Harper & Row, 1965.

Wight, Oliver W. *Production and Inventory Management in the Computer Age,* Cahners Books, Boston, Massachusetts, 1974.

FOOTNOTES

*MIS will be used to represent both MIS and DSS.

**As described in Cooper (1983), decision quality is measured in terms of bias, reliability, volume, etc.

*Some confounding of these conclusions may occur due to violation of constant cost and constant decision quality assumptions. This is explored in depth in section 4.

*F_L represents the first partial derivative of F with respect to L, F_{LL} represents the second partial derivative of F with respect to L, etc.

*Recall that Assumption A asserts that total decision production cost is a non-decreasing function of problem complexity.

*Recall that assumption B asserts that the total cost curve representing the most efficient decision production in low problem complexity will at some complexity level, intersect from below the total cost curve representing the most efficient decision production in high problem complexity.

*Note that since $F_X < 0$, assuming $F_{XX_{low}}$ and $F_{XX_{high}}$ have the same sign, then "complexity having a stronger negative influence" implies that $F_{XX_{low}} < F_{XX_{high}}$.

**Recall that decision volume is one dimension of decision quality.