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Toward Intelligent Management Information Systems

Zenon S. Zannetos

Sloan School of Management

Massachusetts Institute of Technology

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MASSACHUSETTS
INSTITUTE OF TECHNOLOGY
50 MEMORIAL DRIVE
CAMBRIDGE, MASSACHUSETTS 02139

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Abstract

The purpose of this presentation is to venture a little into the future and explore some thoughts on the new generation of management information systems for planning and control. This is done by describing:

(a) What type of information management needs for efficient planning and control.

(b) The stages through which a system must go to acquire the necessary characteristics and intelligence to aid management in its planning and control activities, and

(c) The author's efforts to design information and control systems which have the desirable attributes and intelligence.

While many of the ideas expressed are operational, many others, especially those which refer to associative information systems and the control of the planning process, are speculative.

I. Planning and Control Activities

It is commonly accepted that the information generated today within business organizations is not sufficient for modern managerial needs. To many of us, however, it is not often clear what these needs are. Obviously, unless we define these needs, we will not be able to design an efficient information and control system.

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*The author is Professor of Management at the Sloan School of Management, Massachusetts Institute of Technology.

One can approach the problem of defining the informational needs of management through prescription (normative approach) or description.[1]

The prescriptive approach starts by first postulating the type of activities in which management should be interested. Then on the basis of such postulated activities one determines what information will be required for pursuing these successfully. The descriptive approach, on the other hand, starts with a study and description of the managerial activities and of their information content. Whatever behavior is observed in the process of investigation is then assumed to be amenable to generalization.

My bias, as reflected in this paper, is toward a modified prescriptive approach. The appeal of the prescriptive method is that it provides a structure for challenging the usefulness and logic of managerial activities. To be successful, however, such a method must be modified to encompass non-deterministic behavioral assumptions. The purpose of information systems is to motivate efficient behavior where discretion must be exercised. If these systems fail in this aspect, then they do not generate information, although they may generate a lot of data.

To facilitate the description of information that is necessary for managerial planning and control, let us first establish the nature of these managerial activities. Naturally, the information and control systems of the firm being purposive can only be justified in terms of their contribution toward achieving the objectives of the firm.

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[1] Undoubtedly there are all sorts of possible mixtures of the two and this is amply reflected in the literature on the theory of the firm. See Cooper [1], Cyert and March [2], Marris [3], Papandreou [5], and Simon [6].

The overall managerial planning and control can be divided into three broad categories of activities, planning, control, and replanning.

A. Planning

Under planning we have the following hierarchy of activities at any given level in the management hierarchy.

1. Setting of the Overall Objectives

2. Developing the Substantive Plans for Pursuing the Overall Objectives

3. Translating the Objectives and the Plans to a Whole Chain of Subobjectives and Subplans

4. Evaluating the Various Alternatives and Choosing the Critical Decisions and Operations which are Necessary to Accomplish the Subobjectives and Subplans

5. Budgeting the Plans and the Operations that are Necessary for Achieving the Desirable Objectives

6. Assigning Plans to Responsibility Units

7. Choosing the Appropriate Signals[2] (and implicitly the measurements which will produce them) which will Indicate to Management if Operations are Proceeding According to the Plan and the Plans will Lead to the End Objectives

8. Designing the Information and Control System which will Generate the Appropriate Signals by Comparing the Results from Operations Against the Plans and the Plans against the Objectives

B. Control

For purposes of control, in addition to the activities specified under planning, we need to provide methods which will enable management through the information system to:

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[2] The signals chosen by one level in the management hierarchy normally become the goals for the next lower level. So the control parameters of one level become the planning parameters of another.

(a) Measure and determine deviations from desirable performances.

(b) Co-ordinate the various activities of the firm so that destructive tendencies be minimized and complementarities be exploited.

(c) Encourage learning by making available specialized information.

(d) Motivate those who determine the allocation of resources to do so efficiently.

(e) Provide premises for remedial action within the prescribed plans whenever the circumstances necessitate.

(f) Perform causal diagnosis.

C. <u>Replanning</u>

The information system, in order to be of value to top management, must also provide information for replanning. Afterall, replanning is at the heart of the control system. Traditionally the control process has been designed to encompass mostly <u>operating</u> process control. In other words its scope has been limited to determining whether operations are proceeding according to a <u>given</u> plan. But the <u>planning</u> process itself has been for the most part left outside the scope of the control system. As a result the knowledge gained from operations has not been exploited in a consistent way for better planning.

The dichotomy that we make here between operating and planning process control does not imply independence. As we will point out later, operating process control fits into planning control hierarchically. So in effect we are more or less attempting to draw polarities out of a continuum of abstraction.

Now let us turn to the reasons behind the obvious concentration of attention on operating process control. Is it because of greater pay offs? Of course not. In fact, planning decisions fix the resources and the technology which make operating process control possible. The emphasis on the latter is primarily due to operational ease. In the area of planning

we cannot very easily develop standards of behavior and standard technologies which will permit measurement of deviations. To establish meaningful standards one needs to develop functional relationships of cause and effect. Most relationships as well as the environmental conditions that determine them are, in the case of operating process control, fixed. Although the fixities may not be caused by nature, they are introduced by the value judgements of management and, of course, by operating technology. For example, once management decides to produce a certain product in a given way it becomes relatively easy to establish manufacturing cause and effect relationships.

In the case of the planning process, one is dealing with many more variables than at the operating level. Cause and effect relationships are not well defined and there is a lot of indeterminism. The value premises (judgements) entering into the planning process are far greater than the factual elements. Consequently, changes in environmental conditions now become critical, because it is the composite impact of these environmental conditions that influences intuition, value judgements and planning. Furthermore, the perceptiveness of the planner in associating the proper environment and the changes in it with his plans is what enables him to learn and to make better plans in the future, precisely by deriving causal relationships.

Most activities of the planner have been historically carried out outside the regular management information system, either on an ad hoc basis, or on a memorandum basis, or not at all. With the exclusion of the planning activities from the continuous information system a lot of the data that are necessary for efficient planning are treated as exogenous to the system.

One can readily see the dangers of such processes. First, it is doubtful whether such planning methods will be consistently applied. Second, if they are applied, and benefits are derived therefrom, the knowledge gained remains with those immediately involved in the planning process. The stock of planning knowledge of the organization may not be affected in any significant manner. Hence the benefits of experience are not usually stored in the system to expedite the learning process of an organization. The expertise is left with the planner-doer and therefore apprenticeship and repetition of mistakes substitute for formal training. All of us undoubtedly have heard executives stress that the foremost attributes of a good planner are intuition and experience. Not to underestimate the value of these attributes, I believe that the information system of the firm can do a lot to bring to bear on specific situations handled by specific individuals, at least part of the cumulative intuition and experience of the organization. In this way we can expedite and broaden the learning process and improve overall plans.

We already have pointed out that planning especially at the top, includes many judgemental elements. This complicates matters but the situation is far from hopeless. While no one can assess the efficiency of pure value judgements, the information and control system can provide measurements to establish ex post facto whether, the factual elements of planning led to the value judgements, and even challenge the value judgements. Therefore, to serve in this capacity the information and control system must concentrate on the postulated environmental conditions and the functional relationships implied in the many translations and transformations of objectives and operations. It is in these relationships and assumptions that one finds the "factual" premises of plans and the necessary ingredients of the information

system.[3] Obviously, since plans extend over long periods of time, the information system of the firm must have the capability to sense changes in the environment, to abstract relationships and derive inferences, to be probabilistic and to be sequentially adaptive.

Let us now bring to a close this section of our discussion by stressing a few points in lieu of a summary.

1. The issues affecting the design of the organization structure of the firm were behind almost every argument that we made. It is not our purpose here to examine the factors influencing divisionalization[4] (centralization versus decentralization) but rather to point out that the organization structure of the firm, it appears, must be established as a result of the mutual interaction of: (a) the planning technology, (b) the operating technology and (c) the information and control technology. It is obvious that both the information and control system and the operations are aimed at the implementation of the plans and objectives of the organization. Nevertheless unless the economic characteristics of these three technologies coincide -- something which is very improbable -- then tradeoffs must occur and compromises be made.

2. Because of probable differences in the economics and technologies of planning, operating, and information-control processes, a one-to-one correspondence between particular subobjectives, subplans and suboperations cannot be in general enforced, although in the totality such a correspondence potentially exists.[5] The subdivision invariably occurs for purposes of problem identification and for association of the relevant information and technology for the solution of the problem in a modular fashion. In the process of implementing plans the technical characteristics of either information or operations may necessitate different partitioning of the total plan.

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[3]Every transformation or translation of objectives to subobjectives and operations introduces information and technology, and therefore factual elements to assess the value judgements of the one who established the transformation.

[4]We have analyzed these factors in "On the Theory of Divisional Structures: Some Aspects of Centralization and Decentralization of Control and Decision Making", Management Science, December 1965, Vol. 12, No. 4, Series B.

[5]We must distinguish here between general substantive plans which are aimed at the implementation of overall organizational objectives and operating plans which focus on the particular operation.

3. Therefore the organization structure in an environment of change must be stable in the short run but flexible in the long run. Short-run stability is necessary for problem solution and acquisition of new knowledge, and long-run flexibility for responding to changes in the environment and exploiting the new knowledge.

4. The information system of the firm must cater to both plans and operations. It is in fact the bridge between the two and between the total environment and the firm. Because of its unique role, the information system must be more flexible in general than either organization structures or plans or operations. It must provide relevant information on a one-to-one basis for both planning and operating control, at all levels worth such attention. Hence the information structure must be amenable to both aggregation (through explicit recognition of interdependencies) and partitioning (decomposition) through buffering.[6]

5. Most of the present day integrated information systems are oriented toward operating process control (i.e. are post-mortem systems) because of the tractability of repetitive-standardizable processes. But most planning, especially long-range planning, is not very repetitive. As a result, we cannot afford to wait until we collect enough total planning information and develop through experience habitual response patterns of behavior. Frankly, if we wait we may not survive. Probabilistically speaking, the longer the time span covered by the plans, the more vital are the latter for the success of the organization, and also the greater the correspondence between the success of the organization and that of the plans. Economies of specialization and technological changes enforce upon management consideration of plans of ever increasing time span. However, the longer the time span covered by plans the less repetitive plans become. This in turn implies that (a) those who make the decisions may not remain in the same position long enough to observe the consequences of their plans and decisions and to learn from experience, (b) the probability that a person will make similar decisions often enough to gain habitual response patterns is very small,[7] and (c) the probability of collecting total information on even one plan is small because of changes in the environment over time. Consequently, the planning must be integrated into the total information system of the firm and such information system must possess capabilities for:

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[6]Buffering is necessary for short-run independence.

[7]Within the same organization, however, at any moment of time (at other geographic locations) and over time, similar decisions may be made. That is why a data base for planning is very critical for the firm.

(i) Deriving cause and effect relationships on the basis of insufficient information

(ii) Increasing the lead time between the point that it senses the change and the time period the consequences of such change will become obvious

(iii) Making diagnoses on line and using such diagnostic results for planning prognoses

(iv) Up dating itself.

In effect we need an information system which has associative powers and intelligence, and a system which can learn sequentially and adapt to changes in the environment. With these capabilities the system can act to exploit the information generated by changes in the environment rather than react to such changes.

II. Stages in the Process of Acquiring Intelligence

We will now attempt to roughly describe the stages through which organisms go to acquire intelligence. Although helpful for purposes of exposition, these stages are only arbitrary points in a continuum. As I have previously done in this paper, however, I will once again run the risk of over-simplification in order to fit ideas somewhat neatly into classifications. With this as a face saving qualification, I will attempt to apply some rules for differentiation which I hope will help my exposition.

A possible classification of such evolutionary stages in order of increasing sophistication may include:[8]

1. Capacity to store moduls of raw data. This is a passive absorption or trapping capability. At this stage the storage of data is haphazard, because the system has no rules for inclusion or exclusion. As long as empty storage cells exist, data are stored as sensed.

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[8] These steps are similar to those listed by Marvin Minsky in Computers and Thought, Edward A. Feigenbaum and Julian Feldman (Eds.), McGraw-Hill Book Company, New York 1963, pp. 406-450.

2. Capacity to classify data. A capability for classification implies that the system can perceive differences. It cannot, however, perform automatic control functions because it does not as yet have a perception of desirable behavior to direct its actions nor can it manipulate data.

3. Capacity to extract differences. At this stage the system is still very unsophisticated, but it can recall stored data and, through its capacity to classify homogeneous entities, it can compare and extract differences in the quantitative magnitudes of otherwise homogeneous data. Some primitive operations, such as aggregation, may be within the capabilities of the system. The output of these operations, however, cannot be classified as information.[9]

4. Capacity to store simple cause and effect relationships. In order that an information system acquire diagnostic facilities it must be capable to store cause and effect relationships. The first step in this direction is to store various discrete levels of such relationships and associate with each level a cue for automatic response in case differences are observed between the postulated and actual levels. The transition from the stage of simple matching to extract differences to the stage where cause and effect relationships with their associated cues can be handled effectively by the system, is a very significant step in the evolution toward intelligent systems.

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[9] We can say that data are converted into information if they are associated with an appropriate context to generate meaning. Such associations are transformations and logical operations applied on the data.

5. Capacity to manipulate cause and effect relationships and apply heuristics for simple inference. At this stage the generalized functional (cause-effect) relationships themselves are part of the system, not just the various levels of given models. Consequently, as soon as the system observes the occurrence of a variable, which appears in a stored functional relationship, it can carry out, deterministically, the consequences of such observation.

6. Capacity to infer probabilistically and also challenge the models themselves. The system has now capability for determining the probabilistic significance of deviations, not just reporting them in absolute terms, and adjusting the prior distribution surrounding various cause and effect relationships or models. This in substance is a sequential test and facilitates the development of empirical memory.

7. Capacity to derive more abstract functional relationships from experience. Although some type of associative characteristics were introduced into the system at Stage 4, with the capacity to store simple cause and effect relationships for measuring deviations, real associative powers, that is to say capacities to associate on the basis of incomplete information have not been a part of our system up to this point. Now the system can infer changes in the environment on the basis of incomplete information and associate such information with the functional forms for purposes of updating the latter, and deriving if the evidence requires, of more abstract relationships. At this stage we have not only associative but also fully adaptive capabilities. Furthermore, we have the ingredients for a system which identifies problems before these are manifested or are perceived by humans.

8. Capacity to derive functional relationships for determining the applicability of functional relationships. This stage of course refers to metasystems and I am sure that a lot of us will be very satisfied for the time being, if we succeeded in all other respects but this. To amplify a little on the characteristics of this stage, let us for a moment go back to Stages 4 and 5. At first, in Stage 4, our system acquired capabilities to store output data given various input levels of the model. However, the models themselves were exogenous to the system until Stage 5. This transition to a system which includes functional relationships may be called the bridge between the present accounting system and what we elsewhere called a functional accounting system.[10] Now let us visualize a sophisticated functional system which stores alternative models for the same functional relationships but which is not capable of generalizing. Once it learns to associate information with these alternative models and derive more abstract and more general functional forms then, the bridge between functional and associative systems is established. From this point, we could progress toward heuristics for determining the applicability of alternative functional relationships and toward deriving more abstract relationships of more general applicability.

Intelligence starts with an advanced Stage 4. That is to say unless a system is capable of associating cause and effect, it is merely a storehouse of data most of which are of limited usefulness. The accounting system which is the only integrated and all inclusive information system in operation today is now for the most part at Stage 3, that is to say it is capable of storing, classifying and determining differences. It, therefore, possesses no intelligence according to our definition. Certain parts of it,

[10] "Toward a Functional Accounting System: Accounting Variances and Statistical Variance Analysis" Industrial Management Review, Spring 1966

related to operating process control under standard systems with flexible budgets, are at an elementary Stage 4 with capabilities for on-line real-time diagnostics if computerized. If the model of manufacturing operations is extended to include all other activities of an organization then it will be a relatively simple matter to design an accounting system as described in Stage 5 with prognostic capabilities based on fixed (deterministic) functional relationships. In order to acquire planning process control capabilities, however, a system must enter Stage 7, that is to say it must be capable of deriving abstract functional relationships from experience, on the basis of incomplete information.

III. Efforts Toward Intelligent Management Information Systems

Now I wish to describe some of my efforts toward the development of intelligent management information systems. In the process it will become obvious, but I hasten to stress right now, that a lot of what I will say is still at the hypothesis or speculative stage. At least the most interesting part is so and remains to be done. I am, however, convinced that it can be done, and in many cases I will sketch an approach to the problem.

Among the most central aspects of any information system are the notions of variability and deviations. Through the ability to perceive variations and their consequences, the information system can generate signals for motivating managerial action. It is therefore natural that we focus our attention on the nature and causes of variability.

For purposes of exposition we will start with information systems for <u>operating</u> process control and gradually build up to systems for <u>planning</u>

process control. Control, as will be used in the discussion which follows, includes replanning. Therefore, each one of the sybsystems that we will describe fits modularly into a hierarchical total system.

A. Information for Operating Process Control: Probabilistic

For designing a better operating process control system than the existing managerial accounting systems, we start with the easiest of all situations, those that can be standardized. The standard accounting systems, as we have already mentioned, are the most sophisticated accounting systems in operation. They measure deviations and report variances but not their significance.

In order to obtain the significance of deviations, one must know how probable these are and also what are their consequences. Probabilistic notions can be introduced in the information system if we capitalize on the assumptions underlying the standard accounting systems. These assumptions may not be always sophisticated or even explicit, but they are nevertheless fundamental.

For the successful operation of standard accounting systems, it is necessary that the process which is to be brought under continuous operating control be, for the most part, stable.[11] In other words the process must allow a quantification of its characteristics, and these characteristics must not change substantially over the period chosen for control purposes, if they are to be used as short-run indicators for performance appraisal. But here, as in all cases of accounting measurements, exactness and purity are difficult

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[11]The notion of stability in practice need not be very strict. It can be assumed initially and tested over a large sample or sequentially. Often a person cannot very well determine, especially with certainty, which observations belong to what statistical universe. We can only develop hypotheses and try to prove or disprove these.

to obtain. Even if they could be obtained one should check to find out whether managerial decisions are sensitive to marginal refinements in the data. Therefore, impure data are not necessarily worthless or of little value.

In our case we need sufficient stability in the process to allow the derivation of a tentative standard from which deviations can be measured. We have argued elsewhere [7] that in the absence of any better approximation, rough tentative estimates are necessary to raise questions, bring forward potential problems and accumulate enough planning information to improve subsequent estimates.

The standard accounting systems start with the implicit assumption that the standard is representative of the processes.[12] Consequently it is used as a prescriptive device. If we now assume that the standard is the expected value of the process and obtain an estimate of the statistical variance around it, then we can ascribe an approximate probabilistic significance to the results from operations.[13] This we can do in one of two ways:

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[12]The application of standard control systems reveals assumptions more far reaching than the notion of probabilistic stability. It is often implicitly assumed that the process is deterministic. This is indicated by the fact that all deviations from the standard are assumed to be significant enough to merit the attention of the managers. Again we must stress that these shortcomings of standard systems are not necessarily inherent in the theory but in their application.

[13]Naturally the assumption that the accounting standard is identical to the expected value is not completely correct. We know that standards can be influenced by both managers and employees and therefore can be biased. If the bias is introduced by employees the information system will of course assess the probabilistic significance of deviations from it. Unless therefore, the employees are very sophisticated, it will eventually become obvious that the deviations generated by operations are not stochastic. If now the bias is introduced by management intentionally, then the standard can still be used to measure the extent behavior has been influenced by the bias. In either case, the assumption that the standard is an estimate of the expected value of the process is not really damaging, especially if used in a Bayesian sense.

1. If the results are normally distributed,[14] then we can use our knowledge of the probability area under the normal curve and sort the accounting variances according to their probabilistic significance. All those results which fall within the limits of acceptable tolerance will not be reported, and so the executives will be able to spend their time on the few significant deviations and ponder on their consequences for planning purposes. This method of reduction of the amount of information brought to the attention of executives was applied on an experimental basis to the weekly reports received by the Vice President for Distribution of a large manufacturing firm. The weekly computer printout of accounting variances for the operations under his control contains an average of over 2,000 entries of 10 to 12 columns each. Upon application of some very simple heuristics, provided by the executive, for determination of what is probabilistically a significant variation from standard and what is not, the report, in the week chosen for the experiment, was reduced to 22 entries. Further analysis of these entries revealed that about half of them were picked up because of the conservative heuristics of the Vice President.

2. In cases where normality cannot be assumed and the probability law describing the process cannot be obtained, use of Chebycheff's inequality can provide a substitute for assessing the probabilistic significance of deviations in performance. This test does not, of course, provide results as strong as those obtained where the applicable probability law is known, but a loose probabilistic estimate is much better than no estimate at all.

Closely related to the issues of probabilistic significance presented above, are (a) the degree of data collection, processing and aggregation and (b) the length of the reporting cycle. These in turn will affect the number and frequency of aggregate accounting variances analyzed and the extent of sampling for analysis within the aggregate by subpopulations [7].

Once the first step toward a probabilistic control system is taken, then other features can be added to it easily. What we should be aiming for with each addition, are features which will help us expand sequentially the

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[14] Empirical evidence points out that in most manufacturing operations the results from operations are normally distributed because even the individual observations are averages.

planning and control processes from the smallest activity unit to larger and larger units, with each process interrelated to the next. In this sense, the firm can have an integrated and modular information system which will enable each unit to plan for its own operations, without completely neglecting the natural interactions between itself and other units within the organization. A possible sequence of steps in terms of increasing sophistication and generality might include:

> (i) Application of Bayesian Analysis. Given that several standards are probable, then on the basis of prior-posterior analysis one can check sequentially and determine which one of the standards is more meaningful.
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> There are some difficult but not insurmountable problems to be overcome before the Bayesian framework is applied, one being the determination of the conditional probabilities applicable to the various results from operations given the alternative standards. One possible way of approaching this problem is to assume that the statistical variance is invariant with respect to the different prior standards. Such an assumption will also facilitate the selection of a few among the many alternative standards of performance, and the establishment of the tolerance limits and frequency of sampling in cases where standards are intentionally manipulated by management for motivation.
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> In conjunction with the possible manipulation of standards, I would like to mention a very interesting phenomenon which I have observed within two very large firms, and which I feel merits exposure especially since I believe that it is quite common. It appears that within some firms where "management by exception" is practiced, those who are responsible for setting the standards and controlling on the basis of them, are behaving contrary to logic. The tighter, meaning tougher, they set the standards, the more they watch the unfavorable and ignore the favorable variances. Naturally, the tougher the standards, the greater the probability that unfavorable variances will occur due purely to stochastic reasons, and as a result the more meaningful and worthy of analysis are the favorable rather than the unfavorable variances. In other words, the "exceptions" which contain information are the favorable variances.

(ii) Statistical Analysis of Accounting Variances. After the accounting variances for a particular time period are tested for probabilistic significance they can then be analyzed statistically. In the case of manufacturing operations, the input data needed for the analysis are generated by standard accounting systems [10]. For most other operations encompassed by accounting budgetary control, appropriate data can be generated for this purpose, although these data may not be a routine by-product of existing systems.

The statistical analysis of variance can be performed to determine differences in performance among relatively homogeneous subunits of an administrative unit at a moment of time--say over the accounting period--or to check for shifts in the performance of a unit over time. An analysis of the components of the statistical variance will then focus attention on the reasons for the observed variability in performance, and lead us to elementary cause and effect relationships.

Obviously, one must first choose the variables he wishes to test for significance. The information system cannot, in the absence of heuristics, determine what variables are important enough to introduce into the models to be tested. Once the choice is made, however, either exogenously or through the application of heuristic rules which are part of the system, the system can statistically determine how important these variables are in explaining behavior.

So far we have suggested a method for examining the probabilistic significance of accounting variances which are obtainable in most cases out of good accounting systems (part (i) above), and followed up with some suggestions for testing statistically (a) the average performance of relatively homogeneous[15] subentities during any accounting period, and (b) the performance of subunits over a series of accounting periods. Then, we added an analysis of the components of statistical variances for deriving and testing simple cause and effect relationships; relationships should then be made part of the information system and checked sequentially. In this way, experimental designs can become part of the accounting systems, and if the derived cause and effect relationships incorporate time lags, the systems will then possess some elementary prognostic capabilities. This follows because once an impetus (variation from normal performance or expectations) is observed, the consequences over time can be carried out by the information system automatically, on the basis of stored interrelationships.

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[15] The requirement of homogeneity need not be very restrictive in this case. It does not imply that the subunits must be identical, only that the performance variables should be.

<u>(iii) A Check on Subunit Interdependencies.</u> The variations in performance of a subunit are not only affected by causal factors which originate within the unit itself, but also by variations in the performance or in the planning of other units. So the next step in the development of our integrated information system is to relate unit performance to outside variations and to link the interrelated units in terms of cause and effect mathematical functions.

A possible measure of subunit interdependence can be provided by the statistical covariance. By using covariances rather than correlation coefficients we obtain an index which indicates not only the type of interrelationship and how strongly the chosen subunits are interrelated, but also how significant is their contribution to the total statistical variance of the organization.[16]

The analysis of covariances can focus our attention on those activities within the organization that are strongly complementary or strongly substitutable and give us indications of possible re-arrangements of the organization structure which might increase efficiency and/or reduce overall variances. <u>Normally</u> negative covariances would indicate the need for centralizing the planning and control activities of the interrelated units, while positive covariances would indicate the need for further separation and neutralization. Through stratification of the data, information may also be obtained on the existence of possible asymmetries in the consequences of positive versus negative variations. Such information, coupled with the statistical analysis of the components of the covariance, is necessary for deciding which cause and effect relationships are to be stored into the information system and what type of signals are to be generated.[17] Time lags in the causal relationships can be introduced also at this phase wherever relevant. With each such additional attribute acquired, the information system of the organization becomes more intelligent and more prognostic.

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[16] This is so because of the mathematical relationship which defines the variance of the sum of interdependent variables as equal to the sum of their variances plus twice the sum of their covariances taken two at a time.

[17] For more details on these aspects of the system, see: Zenon S. Zannetos, "Measuring the Efficiency of Organization Structures: Some Implications for the Control System of the Firm" MIT Working Paper #117-65

<u>(iv) Expansion of Covariance Analysis to Neighboring Units.</u> Having applied covariance analysis to determine the critical variables which affect the performance of subunits within a subsystem, we can now extend this analysis to adjoining subsystems.[18] Step by step we keep on interrelating subunits and subsystems until we develop an empirical hierarchical model of interactions within the entire organization. This model then becomes an integral part of the continuous information system. So through an analysis of the operating data we get probabilistic significance of deviations, simple cause and effect relationships and also signals for relative centralization and decentralization.

We must note at this point, that we do not have to apply this analysis to the total organization before it can provide useful information. The analysis can start at any management level, accept initially things as they are, and ask whether, on the basis of the signals generated, operations can be improved through reorganization. Extensions of the analysis can be introduced gradually as new interrelationships are revealed. No matter how partial the information system is therefore, or at what level in the hierarchy it is originally applied, it can still provide, for the operations involved, cause and effect relationships which are useful for planning and learning at that level. Furthermore, as we pointed out, it is modularly expandable.

Another useful byproduct of this analysis is the determination of the most sensitive spots in the organization for introducing change. Given that we have determined, through covariance analysis, which operations or subunits are most influential in causing variations in the performance of others, it appears logical, at least <u>a priori</u>, to concentrate our innovating efforts in these modules. In other words, instead of spreading our efforts thinly over the whole organization we may thus "seed" innovation into these critical modules and let the natural interrelationships within the organization spread it. Conceptually this method is quite appealing and holds promise in the very critical area of utilizing effectively innovative talent which is one of the most scarce resources. Furthermore, the generation and spreading of innovation can, under the total system sketched here, be somewhat controlled. Given that cause and effect relationships are stored into the system, an approximate time schedule and pattern of reaction to change may be traced and used for planning and for subsequent control.

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[18] We in effect develop a covariance matrix of subsystems.

(v) Covariance Analysis over Time. In order to develop prognostic capabilities, the system must be able to predict the consequences of variations and provide enough lead time to allow the affected units to plan. Some prognostic attributes were introduced into the information system at stage (ii) as a byproduct of the statistical analysis of accounting variances. Now we are expanding the sophistication of the system to enable it to check not only on intra-unit but also on interunit interdependencies over time. With these characteristics, the continuous information system of an organization will eventually be capable of identifying potential problems before the executives themselves become aware of them. The importance of such a capability cannot be overstated.

The present state of technology is such that we could have an information system possessing the features described up to this point. Now I would like to speculate briefly on the system which may one day solve our problems in the area of planning process control.

B. Information for Planning Process Control: Associative

In order to design an information and control system for planning purposes, one must resort to methods that are far more sophisticated and intelligent than those needed for controlling operations. Planning is generally performed in an unstructured environment, while operations occur within structures and under preconditions set by the plans. The latter aid us, primarily through the creation of substabilities, in designing information systems for operating process control. It is logical therefore to assume that for efficient planning process information and control systems we need metaplans to serve a similar role.

Planning, of course, encompasses a wide spectrum of activities. It covers decisions about the future that range all the way from the utilization of existing resources in repetitive day-to-day operations, to decisions

about future goals and completely new activities and products. Our efforts, therefore, to draw polarities in planning activities is mainly for purposes of classification. The sophistication of the system that is necessary for efficient planning, drastically increases as one moves away from repetitive activities.

Planning that goes on under repetitive operating conditions is included in the system already described. In fact any planning that is initiated by differences that result from comparisons and well defined cause-effect relationships or heuristics, can be made part of the operating control system, because in essence it is replanning along lines dictated by the original plan. However, non-repetitive, long-range, or strategic planning, although of utmost importance, is not usually part of the continuous information system of the firm, for good reasons. It is very difficult to control, because the substability or structure within which it occurs is for the most part either absent or not obvious.

Long-range planning has among other characteristics the following:

1. It is based on data that are usually generated outside the firm. Consequently, if we wish to incorporate in the continuous information system of the firm planning process control activities, we must first of all broaden the scope of the information system to monitor, on a continuous basis, those critical <u>environmental factors</u> that affect the plans and which are considered in most present systems, exogenous variables.

2. It is based on cause and effect relationships that are not very clearly understood. The information system therefore must acquire capabilities for generating hypotheses, and designing experiments to test them and draw inferences, before it can assist managers in their planning activities and in the control of the resultant plans.

Given that for most planning purposes the functional relationships affecting the plans are not well defined, a simple matching process for extracting differences in the planning variables may not indicate the existence of a problem, let alone carry out the consequences of such differences. What we need here is an information system with pattern recognition capabilities.

3. Unlike operating activities, planning is not so much concerned with the elimination of the observed differences but with the underlying forces and their potential impact on plans. In other words in planning the observed differences are very rarely the problem, but only a signal for probably consequences, since many of the factors which affect long-range planning cannot be brought under the direct control of management in an operating sense. The information system, therefore, must have associative powers so that once it recognizes a pattern on the basis of observed differences, it associates such pattern with a configuration of available resources and functional relationships, derives conclusions and, if necessary, initiates replanning.

4. Planning is not very repetitive; consequently, one cannot depend on habitual response patterns such as those used for operating processes. Furthermore, the information available on any plan at any moment of time is incomplete because of time interdependencies. As a result, the planning activities and their monitoring must be carried out on the basis of incomplete information. Thus if such activities are to be incorporated into a continuous integrated information system, the latter must be capable of drawing inferences on the basis of incomplete information.

All the arguments that I presented above, convince me that associative information systems are the systems of the future. Once the basic associative characteristics are successfully introduced into the system, then the

system can increase its intelligence by proceeding through the same steps that we postulated under Part II of this paper "Stages in the Process of Acquiring Intelligence" with one major difference. Instead of working with data, at this level of abstraction the information system will be dealing with patterns of relationships. It will classify patterns, derive rules of correspondence between patterns of inputs and patterns of functional relationships and plans, associate incomplete information with patterns, design experiments, test hypotheses, derive inferences, deductively update the patterns of functional relationships and inductively develop theories of planning.

Given that one of the most important requirements for an intelligent information system is the capability to associate incomplete information with patterns of interrelationships, if we are to implement such a system even in its most elementary form, we must provide for storage of patterns of relationships. Initially they must be developed exogenously and introduced into the system. From then on the system will change these postulated patterns of interrelationships sequentially by learning from experience. The critical relationships that are necessary for planning purposes are usually between:

(a) signals observed and generated by the information system and planning variables

(b) planning variables and plans

(c) plans at any moment of time and over time

(d) plans and the operations that are necessary for their implementation. (Inherent in these relationships are the value functions by which the consequences of plans are evaluated _a priori_.)

(e) operations at any moment of time and over time

(f) operations and potential outcomes

(g) outcomes at any moment of time and over time

(h) outcomes and utilization of resources

(i) resources at any moment of time and over time

(j) utilization of resources and generation of signals.

The above relationships imply that inputs to the data base of the firm must be multidimensional. For example, the resources of the firm will not be recorded in dollars under a single classification, but possibly in terms of dominant characteristics, capacities per unit time and over time, economic values under alternative uses, and the value these assets were expected to generate if used optimally under the dominant plan that existed at the time of acquisition.

Using a decision-theoretic approach, an associative system can develop statistical decision functions and risk functions to evaluate possible outcomes. For its planning aspects the system can use the signals generated by changes in the planning variables to associate them with probable configurations of the functional relationships as mentioned under (a) through (j) above.[19] For each signal-configuration the information system may then derive a dominant plan and for each dominant plan pick out its associated dominant operating solution.

At this point a comparison may be performed to determine the differences between the new dominant solution and the previous one, and the system may

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[19] The signals generated provide conditional information and serve as data coming out of a sampling distribution. The configurations of functional relationships serve as the states of nature and the various decision functions that follow from such associations.

feed information back for enriching its intelligence. If a change is necessary then the derived dominant solution may in turn be used to determine which characteristics of the resources will be utilized. The information and control system may then compare the values imputed to these characteristics, if such values can be obtained, with the values of the more dominant characteristics of the resources which will not be utilized under the new dominant solution, and again feed information back for improving the stock of planning knowledge.

Having picked out a dominant solution, the information system may search over the dominant characteristics of available resources to determine the scarce inputs over the period covered by the plan. On the basis of its findings it may attempt to remove the constraints one by one by one, impute marginal values, and develop plans for the acquisition and timing of new facilities. Finally, it may propose alternative operating solutions on the basis of different patterns of configurations if the new acquisitions necessitate changes in the dominant solution.

Once a plan is put into operation, the information system may in addition to carrying out the normal control functions periodically search to determine whether there is slack in the system. If slack appears and is not temporary, the system may then search for those alternative dominant solutions which normally require more of the surplus input, and compares them against the existing solution for possible replanning purposes.

IV. Brief Summary

The central theme of this paper has been the information system of the firm, and its potential uses for managerial planning and control. The information requirements for efficient planning and control were analyzed

stressing particularly the needs in the area of long-range planning activities. For the latter it was concluded that one needs systems which are much more sophisticated than those presently available.

The various stages through which the information system of an organization may undergo to acquire intelligence were then analyzed. On the basis of the system of classification proposed in this paper, it appears that the traditional accounting systems do not at present possess intelligence even of the most rudimentary form. Influenced by these conclusions, I then set to describe my research efforts toward the development of intelligent information systems. The discussion was separated into two parts, one dealing with operating process control, and the other with planning process control. A probabilistic information system for operating process control was suggested which attempts to integrate short-run control, the redesign of the organization structure of the firm, and the determination of those critical areas within the organization which can most efficiently spread innovation. In this type of system one can incorporate functional forms to derive cause and effect relationships and estimate the consequences of deviations in performance.

Finally, I attempted to sketch the characteristics of an information system which associates signals and incomplete information with patterns or configurations of interrelationships for planning purposes. This I feel is necessary if we are to develop within organizations a transferable stock of planning knowledge to be used for efficient and systematized long-range planning activities.

As I have previously mentioned, I cannot claim that I have solved even a small fraction of the problems inherent in the development of integrated

associative information systems. But as this exposition indicates, there are several intermediary stages, in terms of intelligence, between the types of information systems we now have and those we deem desirable. So there is plenty of room for progress, and I hope that this exposition has made some contribution toward this end.

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