Information Structures Exploration as Planning for A Unitary Organization

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Abstract

Planning behavior for a unitary organization is introduced. In particular, a corollary showing how the planner should acquire information is provided in that the information structure of multiple, independent variables obtained should be at least as valuable as the current one. The planning behavior model also considers the case where goal setting is incorporated in terms of probability density functions of the states of the world. The approach introduced links information economics to planning, and depicts explicitly information processing of the planner in making plans.

Keywords: Small Worlds, Contingent Decisions, Organizations, Bayes's Theorem, Information Structures, Planning Behavior

JEL categorization preferences: C0, R0

I. Introduction

The paper provides a theoretical basis for an improved understanding of the logic of planning, taking into account information processing. Much has been said about planning methods, i.e., how planning problems should be approached. The behavior of planners and decision makers in making and carrying out plans has seldom been addressed (exceptions include Knaap, Hopkins, and Donaghy, 1998; Schaeffer and Hopkins, 1987;Scheshinsky and Intriligator, 1989). In previous attempts to explore planning behavior, the proposed planning procedure has not been described explicitly in terms of how information is processed. The central theme of the paper is that in general planning, like decision making, can be seen as practice of gathering information from which judgments on preference and probability are made. Planning behavior, as in choice behavior, has thus to do with probabilistic and value judgments (March, 1978). The crucial distinction between planning and decision making is that planning considers a set of related decisions at the same time while decision making chooses from a set of alternatives the best based on some criterion. Decision making is an economic activity in that it searches for the best or optimal use of limited resources to attain objectives (Marschak and Radner, 1978, p. 3). Since planning is concerned with gathering information and organizing decisions accordingly, planning behavior is also an economic activity.

Planning and organizational design are partially substitutable. Both are ways to coordinate actions to achieve desired outcomes. The ways in which actions are related in the two forms of activity are different. In an organization, actions are coordinated through explicit structures of decision making and problem solving (Cohen, March, and Olsen, 1972). For example, different decision makers have access to different decision making occasions which tend to vary in terms of capabilities of resolving different problems. In planning, there are no such explicit structures confining which decision makers can attend to which decision making occasions and which problems resolved by which decision making occasions. Planning tends to focus on relatedness of actions in time and space, i. e., temporal and spatial decision making.

There is no sharp conceptual distinction between planning and organizational design in that most planning takes place in organizational contexts, such as corporations, firms, and governments. It is difficult to define planning in any exclusive way, but at least we can identify that planning enhances decision making by reducing uncertainty (Friend and Hickling, 1997; Hopkins, 1981). Organizations are artifacts designed for coordinating actions, i. e., arranging sequences of actions to achieve certain goals. A plan is a set of related, contingent decisions; therefore, planning and organization are in part interchangeable (Lai and Hopkins, 1995). It is crucial, however, to distinguish between planning with respect to substantive decisions and planning with respect to planning activities (Hopkins, 1981). I provided a typology of planning behavior taking into account such distinction (Lai, 1998). In that typology, eight types of planning behavior were distinguished in terms of whether problems are internal or external to the organization; whether the decision making entity is single or multiple persons; and whether decisions are about substantive problems or about plan making. I then ran a set of simulations focusing on a particular type of planning for an organization resolving external problems through making substantive decisions, to explore effects of planning on organizational choice behavior. Interesting findings were reported in that planning might increase decision making efficiency, but not necessarily resolve more problems. In this paper, based on a different approach, I explore planning behavior of a similar type. In particular, I focus on planning in the simplest form of organization, a unitary, coherent organization of individuals with consistent preferences, as a starting point to explore how planning should take place in organizational contexts. Incremental improvements on the present model can be made to match more realistic situations, and tested empirically in real or laboratory settings.

The approach I take in the paper is information economics. Viewing planning as information gathering and organizations as settings of information exchange among their members for making decisions, I investigate how such activities should be carried out optimally to yield desired outcomes. Using information economics to describe planning behavior for land development has been studied (Schaeffer and Hopkins, 1987). Instead of leaving detailed transformations of information structures unspecified as formulated earlier, I take one step further here to describe how information and plans should be processed and made in planning for a unitary organization.

II. Background

The theoretical basis for interpreting planning behavior is utility theory. Planning is defined here as a sequence of information gathering activities to reduce different kinds of uncertainties (Hopkins, 1981), and to solve problems encountered by planners to improve decision making by coordinating related decisions in time and space based on such information. The results from these activities could be either plans (or sets of decisions) or no action, depending on whether planning yields benefit. A plan is a set of related, contingent decisions taking into account these uncertainties (e.g., Hopkins, 1981; Schaeffer and Hopkins, 1987). Though planning is not equivalent to decision making as argued earlier, from a normative point of view, both are problem solving activities, and therefore their theoretical underpinnings must share some commonality. A more comprehensive understanding of planning begs a long research agenda. Without pretending to provide such an agenda, the research is aimed at addressing planning in a narrower context. The interpretation presented here is thus based on normative decision theories because these theories prescribe how people make decisions and are deductively justified (e.g., utility theory in Savage, 1972; von Neumann and Morgenstern, 1947). I am, therefore, interested in how planning should take place, rather than how planning does take place, for the decision maker. In the simplest terms, decision making selects from a set of the best alternative that maximizes expected utility, while plan making coordinates a set of contingent decisions so that making plans yields benefits.

A planner is a person who makes plans and acts accordingly. The descriptive aspects of planning are, of course, relevant and need future work. Similar attempts have been made to describe planning behavior for planners (e.g., Knaap, Hopkins and Donaghy, 1998; Schaeffer and Hopkins, 1987). The approach taken here considers how information structures should be searched yielding the maximum expected utility or payoff. The interpretation will be based mainly on Marschak and Radner's and Savage's choice theory under uncertainty (1978; 1972). I focus here on a simplified planning situation consisting of a unitary group of planners and the environment, or the grand world and the corresponding small worlds (in Savage's language), in which events occur. The unitary group also makes collective decisions as will be introduced shortly. To simplify, I call such a group a planner. In Savage's choice theory, a sequence of assumptions and postulates are made to derive, for an idealized person or for that matter a coherent group, personalistic probability and utility in making choices among acts under uncertainty. These assumptions and postulates are the substance of rationality.

Savage introduces the notions of 'small worlds' and the 'grand world' and the decision maker is to choose the best act in a small world. The concept of small worlds provides a useful way for describing the logic of planning. For example, a small world consists of a set of states or descriptions about the world, and the actions available to the decision maker with the associated consequences given each state. A small world is, in a sense, the cognitive representation of the problem that the decision maker is to solve.

Events are subsets of the set of states. Personalistic probabilities are assigned to these events. In the planning context, small worlds are the planner's perspectives about planning problems. The planner makes decisions in his or her own small worlds which are defined in the grand world. The planner makes plans and then act accordingly, reminiscent of orders sent from the observer to the actor in a two-person team (Marschak, 1974), except that the observer and the actor are the same person in the unitary organization case. In following these plans, the planner chooses among the alternative actions suggested by the plans to solve problems. The planner could revise these plans if unexpected events occur. All such planning activities can be described in terms of primitives as will be discussed in more detail. Most of these primitives are defined rigorously by Savage (1972). I introduce them here in the context of planning.

III. Basic Concepts

The planner as a decision maker is rational in Savage's sense. That is, he or she behaves according to Savage's assumptions and postulates of rationality and is a utility maximizer. In the simplified planning situation of the unitary organization, two worlds are considered: the grand world and the planner's world (a small world). The planner's world is, in Savage's language, a microcosm so that the criterion of maximizing expected utility can be applied to making choices among acts.

Each of the two worlds is described by a collection of states, actions available to the decision maker, and the consequences resulting from these actions. The states in small worlds are subsets of the states in the grand world, or the states in the grand world are the elementary states for small worlds. Let the grand world be, for example, the outcome of tossing two coins simultaneously. Note that Savage used the example of eggs conditions to explain the small world and other concepts. My using the example of tossing coins here may be more concrete. A small world would be the outcome of one of the two coins, regardless of the outcome of the other. The state of the small world, a head for example , is a subset of two states in the grand world (i.e. the outcome of the other coin can be either a head or a tail).

Events are subsets of the states in a small world. In the example of tossing a coin, the outcome of a head is an event. The outcome of either a head or a tail is also an event. Subjective probabilities are assigned to these events to express the planner's degrees of belief in the occurrence of such events. For example, the probability that a head occurs is usually 1/2. The probability that either a head or a tail occurs is one.

A decision is the planner's choice of acts (or actions) from a given set in a small world to solve problems and to anticipate desired consequences. An act will result in consequences which in turn are expressed as a function of the act. The consequences resulting from the act chosen in the small world can be realized in the grand world as acts which in turn results in consequences in the grand world. A small world could evolve resulting in transformations from one world to another. All these concepts can be expressed in functional terms as will be shown in the following sections.

A planning problem is thus a problem of modifying the current states in the planner's world to achieve the desired states, taking into account future contingencies. This modification would require a set of acts, or decisions or a plan, which would in turn result in unexpected consequences. Strictly speaking, a plan is a set of related decisions or choice alternatives conditional on events with various probability distributions. A planning activity is a set of actions taken by the planner in the planning process. I consider the case in which planning occurs in a discrete time frame in that a plan is made in each time period for solving the planning problems anticipated during that period. A new plan may or may not be formed for the next time period while the old one discarded. The process continues until the planner is satisfied with the current states or the planner's resources are depleted. A discussion of the dynamic planning problem is beyond the scope of the paper. Because of limited space I focus here instead on information processing for a single time period. That is, I study how information should be gathered in making plans for the unitary organization.

IV. Small Worlds and the Grand World

Before constructing my model, some basic ideas on small worlds and the grand world are introduced based on Savage's notions (1972, pp.8-17). However, I elaborate these ideas more to fit my purposes presented in the following sections. A small world is a confined decision situation derived from the grand world for making one decision, whereas a plan begs coordination of a set of decisions, a set of small worlds. In the small world there exists a mapping from a set of states into consequences through actions. Savage did not define explicitly and mathematically what states are except for a verbal explanation that a state of the world is "a description of the world, leaving no relevant aspect undescribed" (1972, p. 9). I provide a broader definition of states here as follows:

Definition 1: States

States are the realized outcomes of a set of independent random variables.

For example, let X be a set of *m* independent random variables, $X_1, X_2, X_3, \ldots, X_m$, of which the values are real numbers, representing the grand world. The vector $(x_1, x_2, x_3, \ldots, x_m)$ is a state of the grand world. Assume the number of the possible values for each random variable is finite. That is, each random variable can be defined on a particular finite sample space. It follows that the number of the total states are also finite. A state of a small world is a subset of the elementary states in the grand world. For example, the outcomes resulting from the vector of independent random variables ($\vee$, $X_i, X_{i+1}, \ldots, X_{i+k}$, $\vee$)are the states of a particular small world where $\vee$ denotes the random variables that are irrelevant to the current decision situation and can be ignored, although they do exist. The grand world can thus be represented by a Cartesian product across the set of independent random variables under consideration, i.e., $X_1 \times X_2 \times X_3 \times \ldots \times X_m$.

Alternatively, the state in a small world can be any subset of the states in the grand world. Consider throwing a pair of dice. If the 36 outcomes represent all the states in the grand world, the events that the two dice show up even points simultaneously are the states in a particular small world, and are subsets of the states in the grand world. States in a small world are in some sense events in the grand world. The decision maker's degree of belief that a state is realized depends on the joint probability distribution across the independent random variables under consideration. Therefore, for each world, whether a small world or the grand world, there is a probability distribution characteristic of the states in the world. The derivation of such a joint probability distribution is beyond the present scope.

An act is action committed to a decision and taken by the decision maker capable of implementing the action in order to yield expected consequences. Consequences are anything that could happen to the decision maker and he or she is concerned. The notions of acts and consequences introduced here are the same as Savage's (1972, pp. 3-17]. More formally,

Definition 2: Acts

Acts are functions that map states into consequences.

Strictly speaking, there is uncertainty in the mapping between acts and consequences because that mapping is contingent on situations imposed by Nature. For simplicity, I assume that the functions are deterministic, eliminating stochastic factors of such mapping.

According to Savage, a small world is an isolated decision situation in that only subsets of the elementary states in the grand world concern the decision maker, and that only a set of admissible acts are available for the decision maker resulting in various consequences for given states (Savage, 1972, p. 14). Uncertainty plays an important role in deciding an act because no prior knowledge exists about which small world state would obtain. The best the decision maker can do is to select the act yielding the maximum expected utility among those in the available set. Measurements of probability distributions of all possible states and utilities of consequences are central in making such decision. Savage provides a general axiomatic system proving that under strict conditions, such measurements are theoretically attainable and that the decision maker should act accordingly (1972). He coined the term 'microcosm' to represent a small world in which such probability and utility measurements derived from the axiomatic system exist. In my exposition of planning behavior, I treat small worlds as microcosms so that subjective expected utility theory can be applied in my explanations. Savage's notion also implies that there is a close interplay between a small world and the grand world. More specifically, a small world consequence is an act in the grand world that triggers further consequences in the grand world. Therefore, an act in the small world will lead indirectly to the corresponding consequences in the grand world.

V. Extension of the Small World Concept

Single contingent decisions

Decisions can be made regardless of whether more information has been acquired. Contingent decisions are decision rules that prescribe how decisions should be made in light of new information. A plan consists of a set of contingent decisions. Planning is equivalent to gathering information to reduce uncertainty to make contingent decisions (Friend and Hickling, 1997; Hopkins, 1981; Hopkins and Schaeffer, 1985; Schaeffer and Hopkins, 1987). In this section, we provide a theoretical basis prescribing how such a contingent decision should be made.

Following Marschak, assume, with slight modifications, the planner of the unitary organization performs two kinds of activities (1974):

1) To make an observation (gather information) on the external world (grand world), and

2) To perform an action upon the external world based on the information gathered.

In order to take into account explicitly of planning behavior and how small worlds are constructed accordingly, the above activities can be reformulated. That is, in addition to the above two kinds of activities, the planner specifies a desired small world through changing the probability distribution of the states in that world. This planning under goal setting will be discussed following a simpler situation in which the planner gathers more valuable information without anticipating changes in the probability distribution of the states. Though the following axiomatic construct and notations are closely based on Marschak and Radner's formulation (1978), I aim at here interpreting the normative information gathering process in planning through more rigorous terms in combination of Savage's work as depicted earlier. Most of the following equations, e. g., (1) through (7) and theorems, e. g., Lemma 1, are derived directly from Marschak and Radner's formulation with slight modification to incorporate multiple, independent random variables to provide a theoretical context for my illustration of planning behavior. More specifically, the following argument follows exactly the argument of Marschak and Radner, but generalizes it to the case of multiple, independent random variables. Thus I have modified their equations by adding subscripts to account for multiple instances. The important point is to note that as long as the multiple variables have independent distributions that the argument of Marschak and Radner for a single variable still holds, e. g., Theorem 1. The following elaboration can therefore be considered as an extension of their original work.

Let x_k^i be a state in the grand world for a particular random variable X_i, for k = 1,2, . . . , p. Each player gathers information through an information gathering process, or information structure (Marschak and Radner, 1978), η_i, which yields a set of signals y_j^i, j = 1,2,...,n, forming n partitions for the outcomes of the random variable of the grand world. Each grand world state x_k^i corresponds to a signal y_j^i. The states in a small world are thus the partitions in form of the signals.

Following Marschak and Radner, the action performed by a planner is determined by a decision rule α_i and the structure (η_i,α_i) establishes the "organizational form" of the planner's decision situation which is equivalent to a small world according to my definition. Given the information structure η_i and the true state of the grand world x_k^i, the information signal y_j^i is determined by $y_j^i = \eta_i(x_k^i)$; the payoff function for the planner can be denoted as

$$\omega_i\left(x_k^i,a_i\right)=\omega_i\left[x_k^i,\alpha_i\left(y_j^i\right)\right]=\omega_i\left[x_k^i,\alpha_i\left(\eta_i\left[x_k^i\right]\right)\right], \tag{1}$$

where a_i is an action taken in light of the signal y_j^i and the decision rule α_i. Assume the probability density function on x_k^i to be ϕ_i. The expected payoff for the planner considering all the possible grand world states becomes

$$U=\sum_{k=1}^{p}\omega_i\left[x_k^i,\alpha_i\left(\eta_i\left[x_k^i\right]\right)\right]\phi_i(x_k^i)\equiv\Omega(\eta_i,\alpha_i;\omega_i,\phi_i). \tag{2}$$

The problem is then to determine the uncontrolled organizational form (η_i,α_i) such that U is maximized. Note that ω_i and ϕ_i are noncontrollable and that α_i is a contingent decision in that the decision will be made based on the information gathered η_i about the true state x_k^i, i.e., $\eta_i[x_k^i]$. Solving this problem for all random variables in one time period is equivalent to making plans through gathering information (η_i) which are contingent on the resulting signals and the true states of the grand world that evokes indirectly different decisions based on the decision rule α_i. Plans consist of contingent decisions which can be evaluated based either on the states of the environment or on the signals or information. If the relation between the signals and the states, that is η_i, is known, selection of decisions based on any one of the two particular sets of arguments is sufficient as shown above.

One way to explore the characteristics of the best decision rule α_i is to fix η_i, thus leaving only α_i to the planner's choice. "The expected payoff yielded by the best decision function, given the information structure η_i,"(Marschak and Radner, 1978, p. 50) is denoted by

$$\hat{\Omega}(\eta_i;\omega_i,\phi_i) = \max_{\alpha_i} \Omega(\alpha_i,\eta_i;\omega_i,\phi_i) \tag{3}$$

Let $\eta_i[x_k^i] = y_j^i$. The consequences of an action, $\alpha_i(y_j^i)$, are unknown to the planner because there is more than one state corresponding to the signal y_j^i. In this situation, the best decision rule must be selected so as to maximize the conditional expectation of the payoff, given that the true state x_k^i is in y_j^i because a signal is a subset of states. That is, to maximize the expected payoff for a given decision function

$$U = \sum_{k=1}^{p} \omega_i\left[x_k^i, \alpha_i\left(\eta_i\left[x_k^i\right]\right)\right]\phi_i\left(x_k^i\right) \tag{4}$$

We can "group the state x_k^i according to the corresponding signals $y_j^i = \eta_i[x_k^i]$" and "the expected payoff above can be rewritten as"(Marschak and Radner, 1978, p. 51)

$$U = \sum_{j=1}^{n} \sum_{x_k^i \in y_j^i} \omega_i\left[x_k^i, \alpha_i\left(y_j^i\right)\right]\phi_i\left(x_k^i\right). \tag{5}$$

“Choosing a decision function α_i that maximizes U above is equivalent to choosing, for each signal y_j^i,” “ an action $\alpha_i\,(y_j^i)$ that maximizes the term”(Marschak and Radner, 1978, p. 51)

$$\sum_{x_k^i \in y_j^i} \omega_i\left[x_k^i, \alpha_i\left(y_j^i\right)\right]\phi_i\left(x_k^i\right) = \sum_{x_k^i \in y_j^i} \omega_i\left[x_k^i, \alpha_i\left(y_j^i\right)\right]\phi_i\left(x_k^i \middle| y_j^i\right)\pi_i\left(y_j^i\right)$$

$$= \pi_i\left(y_j^i\right)\sum_{x_k^i \in y_j^i} \omega_i\left[x_k^i, \alpha_i\left(y_j^i\right)\right]\phi_i\left(x_k^i \middle| y_j^i\right), \tag{6}$$

where $\pi_i(y_j^i) = \sum_{x_k^i \in y_j^i} \phi_i(x_k^i)$ and $\phi_i(x_k^i \mid y_j^i) = \dfrac{\phi(x_k^i)}{\pi(y_j^i)}$ are, respectively, the probability that the signal y_j^i is received and the conditional probability of x_k^i ,given that x_k^i is in y_j^i. Maximizing (6) is equivalent to maximizing each $\sum_{x_k^i \in y_j^i} \omega_i[x_k^i, \alpha_i(y_j^i)]\phi_i(x_k^i \mid y_j^i)$. The overall expected utility of a decision function α_i is

$$U = \sum_{j=1}^{n} \pi_i\left(y_j^i\right) \sum_{x_k^i \in y_j^i} \omega_i\left[x_k^i, \alpha_i\left(y_j^i\right)\right]\phi_i\left(x_k^i \middle| y_j^i\right). \tag{7}$$

This leads to the following lemma.

Lemma 1:

“For α_i to be a best decision function corresponding to the random variable X_i in the grand world, it is necessary and sufficient for every y_j^i with positive probability, that α_i (y_j^i)be an action that maximizes the conditional expected payoff given $\eta_i(x_k^i) = y_j^i$.”

(Marschak and Radner, 1978, p. 52)

The above formulation is confined to the assumptions that the decision rules or functions are determined for one time period and that the probability density function for the states of the grand world, ϕ_i, is given. It is possible that the planner would also select the goal of changing that probability density function in making plans, which will be addressed following the exposition of a prescribed information gathering procedure.

Multiple, independent contingent decisions

I have shown, based closely on Marschak and Radner's work (1978, pp. 51-52), how a best decision function for a particular random variable in the grand world should be determined so as to maximize the conditional expected payoff given an information structure for that variable. When the planner needs to make more than one contingent decision based on signals corresponding to multiple random variables in the grand world, how should he or she make such decisions? Consider m random variables $X_1, X_2, X_3, \ldots,$ X_m. Lemma 1 depicts the overall expected utility of a decision function α_i and the best decision function is to maximize that utility. Because the random variables are independent as assumed, maximizing the conditional expected utility of a decision function for each random variable given the corresponding information structure is equivalent to maximizing the overall expected utility of the decision functions for all random variables under consideration given the respective information structures. Without loss of generality, assume for each random variable that there are p states and n signals or partitions of the states. Thus (7) can be rewritten as

$$U = \sum_{i=1}^{m} \sum_{j=1}^{n} \pi_i\left(y_j^i\right) \sum_{x_k^i \in y_j^i} \omega_i\left[x_k^i, \alpha_i\left(y_j^i\right)\right] \phi_i\left(x_k^i \middle| y_j^i\right) \tag{8}$$

According to Lemma 1 and (8), we can write Theorem 1 of best independent contingent decisions, not just one decision as depicted by Marschak and Radner in Lemma 1, as follows:

Theorem 1: Best Independent Contingent Decisions

For α_1 , α_2, α_3, . . . , α_m to be the set of best decision functions corresponding to the random variables X_1,X_2,X_3.,. . . , X_m in the grand world, it is necessary and sufficient for every y_j^i with positive probability, i = 1, 2, 3, . . . , m, that α_i (y_j^i) be an action that maximizes the conditional expected payoff given η_i(x_k^i)= y_j^i, for j = 1, 2, 3, . . . , n and *k = 1, 2, ,3, . . . , p.*

VI. Information Gathering: Searching for More Valuable Information

The previous section provides a theoretical foundation of determining best decision rules given information structures. It is possible to compare values of different information structures to prescribe how information should be gathered. Following Marschak and Radner (1978, p. 51), the criterion for comparing two distinct information structures is based on the total expected payoffs yielded by the two information gathering functions. That is, let η_1^i and η_2^i be distinct information structures with respect to random variable

X_i. η_1^i is not more valuable than η_2^i , relative to a payoff function ω_i and a probability distribution ϕ_i, if

$$\hat{\Omega}\left(\eta_1^i;\omega_i,\phi_i\right) \leq \Omega\left(\eta_2^i;\omega_i,\phi_i\right), \tag{9}$$

where $\hat{\Omega}\left(\eta_i;\omega_i,\phi_i\right)$ is the maximum expected payoff

$$\max_{\alpha_i} \sum_{x_k^i} \omega_i\left[x_k^i, \alpha_i\left(\eta_i\left[x_k^i\right]\right)\right]\phi_i\left(x_k^i\right) \tag{10}$$

Note that the comparison of (9) does not take into account the cost of information. There are two approaches to such comparison: fineness and garbling (Marschak and Radner, 1978). One information structure η_1^i is said to be as fine as another η_2^i if η_1^i is a subpartition of η_2^i; that is, if every set in η_1^i is contained in some set in η_2^i. If η_1^i and η_2^i are distinct, and η_1^i is as fine as η_2^i , then we shall say that η_1^i is finer than η_2^i (Marschak and Radner, 1978, p. 53). Two information structures are noncomparable in the sense that none of the information structures is finer than the other. "The finest possible information structure is complete information, defined by"

$\eta_i\left[x_k^i\right] = \left\{x_k^i\right\}$ for all x_k^i in X_i. (Marschak and Radner, 1978, p. 54) (11)

"The least fine (or "coarsest") information structure is the partition consisting of the set X_i itself." (Marschak and Radner, 1978, p. 54) This structure contains no information. "It is clear that this information structure gives no information at all that has not already been incorporated into the formulation of the decision problem."(Marschak and Radner, 1978, p. 54) It is desirable to obtain finer information structures due to the following theorem which is directly derived from Marschak and Radner (1978). The proof can be found in Marschak and Radner (1978, pp. 54-55).

Theorem 2:

"Let η_1^i and η_2^i be distinct information structures; if η_1^i is as fine as η_2^i , then, and only then, η_1^i is at least as valuable as η_2^i for every probability density and every payoff function, that is,

$\Omega\left(\eta_1^i;\omega_i,\phi_i\right) \geq \Omega\left(\eta_2^i;\omega_i,\phi_i\right)$ for all ω_i and ϕ_i. Marschak and Radner, 1978, p. 54) (12)

In order to provide the other approach to comparing information structures, namely garbling, two notions on payoff-adequate partitions and noisy information structures are introduced.

Definition 3: Payoff-adequate Partition (Marschak and Radner, 1978, p.59)

"A partition Z_i of X_i is a payoff-adequate partition if it is sufficiently fine, with respect to the payoff function ω_i, in the following sense; for every set z_i (event) in the partition, every pair x_1^i, x_2^i of states in z_i, and every action a_i,

$$\omega_i(x_1^i, a_i) = \omega_i(x_2^i, a_i)." \quad (13)$$

Definition 4: Noiseless Information Structure (Marschak and Radner, 1978, p. 60)

"The information structure η_i is said to be noiseless (with respect to Z_i) if, for each z_i in Z_i, the conditional probability distribution $\pi(y_j^i|z_i)$ assigns probability one to some signal; otherwise η_i is said to be noisy."

Noiseless information in some sense means cleanliness or purity of information. If the signal yielded through an information structure can be fully related to the payoff of a particular decision situation, then the information structure is noiseless. "An average stock price is an example of a noiseless information structure, whereas a market survey would . . . turn out to be noisy" because the outcome depends on many unknown variables (Marschak and Radner, 1978, p. 60).

Based on the two definitions the well known Bayes's theorem relating the prior and posterior probabilities, and the conditional probabilities $\pi(y_j^i|z_i)$ can be described as follows:

Theorem 3: Bayes's Theorem (Marschak and Radner, 1978, p. 63)

For any two sets z_i and $z_i^{'}$ in Z_i,

$$\frac{\pi_i\left(z_i \mid y_j^i\right)}{\pi_i\left(z_i^{'} \mid y_j^i\right)}=\frac{\pi_i\left(y_j^i \mid z_i\right)\pi_i(z_i)}{\pi_i\left(y_j^i \mid z_i^{'}\right)\pi_i(z_i^{'})} \quad \text{or} \quad \pi_i(z_i \mid y_j^i)=\frac{\pi_i\left(y_j^i \mid z_i\right)\pi_i(z_i)}{\sum_{z_i^{'}\in Z_i}\pi_i\left(y_j^i \mid z_i^{'}\right)\pi_i(z_i^{'})}. \tag{14}$$

A more concrete definition of comparing information structures with respect to a particular payoff-adequate partition is given as follows:

Definition 5: Garbling Condition (Marschak and Radner, 1978, pp. 64-65)

Given two information structures with respective partitions Y_i *and* $Y_i^{'}$ *and a payoff-adequate partition* Z_i, *if the joint probabilities of* z_i, y_j^i, *and* $y_j^{i'}$ *of sets in* Y_i, $Y_i^{'}$ *and* Z_i *respectively:*

$\pi(y_i^{i'} \mid z_i \cap y_j^i)$ *is independent of* z_i, *for all* $z_i \in Z_i$, $y_j^i \in Y$ *and* $y_j^{i'} \in Y'$, *then* $Y_i^{'}$ *is a garbling of* Y_i.

It is clear that a garbling has no bearing on payoff and is derived from another information structure. It can be proved for the following theorem (Marschak and Radner, 1978, p. 65):

Theorem 4:

"If $Y_i^{'}$ *is a garbling of* Y_i, *given* Z_i, *then* Y_i *is at least as valuable as* $Y_i^{'}$, *given* Z_i."

The problem of garbling is indicative of accuracy of information, and thus is crucial in planning research because it is one of the most fundamental forms of uncertainty. Problematic garbling pervades in information based on which plans are made, regardless of whether the information is about environment, values, related decisions, or search among alternatives (Hopkins, 1981). Planning in some sense is equivalent to eliminating problematic garbling and acting accordingly.

The planning problem under the current formulation boils down to searching for the coarsest information structure which the current information structure available is a garbling of, and is noiseless with respect to the payoff-adequate function. Put simply, the information gathered in a particular planning situation must be both accurate and relevant to the planner's payoffs. Before giving the complete proof of this corollary of my model of information searching, I need first to prove the following theorem of my own.

Theorem 5:

Given two distinct information structures η_1^i and η_2^i and the respective payoff-adequate partition Z_i, if η_1^i and η_2^i are noiseless and noisy with respect to Z_i respectively, and Y_1^i and Y_2^i are partitions of X_i induced by η_1^i and η_2^i respectively, then η_1^i is at least as valuable as η_2^i.

Proof: According to (10), $\hat{\Omega}(\eta_i;\omega_i,\phi_i) = \max_{\alpha_i} \sum_{x_k^i} \omega_i[x_k^i, \alpha_i(\eta_i[x_k^i])]\phi_i(x_k^i)$. Grouping x_k^is according to Z_i, and η_i, and from (7), we have

$$\hat{\Omega}(\eta_i;\omega_i,\phi_i) = \sum_{z_i \in Z_i} \sum_{j=1}^{n} \pi_i(y_j^i \mid z_i) \max_{\alpha_i} \sum_{x_k^i \in y_j^i \cap z_i} \omega_i[x_k^i, \alpha_i(y_j^i)]\phi_i(x_k^i \mid y_j^i \cap z_i). \tag{15}$$

Because η_1^i is noiseless with respect to Z_i, by definition, $\pi_i(y_1^i|Z_i)$ is equal to one for some $y_1^i \in Y_1^i$ that contains z_i, those for all other y_1^is being zero. In addition, $y_1^i \cap z_i = z_i$ for $\pi_i(y_1^i|z_i) = 1$; otherwise $y_1^i \cap z_i = \phi$. Equation (15) boils down to

$$\hat{\Omega}(\eta_1^i;\omega_i,\phi_i) = \sum_{z_i \in Z_i} \max_{\alpha_i} \sum_{x_k^i \in z_i \text{ and } y_1^i \in Y_1} \omega_i[x_k^i, \alpha_i(y_1^i)]\phi_i(x_k^i \mid z_i). \tag{16}$$

Consider the conditional probability $\pi_i(y_2^i|z_i)$, for every $z_i \in Z_i, y_2^i \in Y_2$. Because η_2^i is noisy, $0 \le \pi_i(y_2^i \mid z_i) < 1$, for every $z_i \in Z_i$. Let

$$\pi_i(y_2^i \mid z_i) = \sum_{y_1^i \in Y_1^i} \beta_{y_2 y_1} \pi_i(y_1^i \mid z_i). \tag{17}$$

It follows that

$$\sum_{y_2^i \in Y_2^i} \beta_{y_2 y_1} = 1 \text{ for every } y_1^i \in Y_1^i \tag{18}$$

because $\pi_i(y_1^i|z_i)$ is, by definition of noiseless, equal to one for some $y_1^i \in Y_1^i$, and we can set $\beta_{y_2 y_1}$ to $\pi_i(y_2^i|z_i)$ for that y_1^i, all other $\beta_{y_2 y_1}$ s being set to arbitrary values so that $\sum_{y_2^i \in Y_2^i} \beta_{y_2 y_1} = 1$ and Equation (17) hold ($\pi_i(y_1^i|z_i)$ is equal to zero for all other y_1^i s).

Equations (17) and (18) imply that Y_1^i is at least as valuable as Y_2^i so that $\Omega(\eta_1^i;\omega_i,\phi_i) \geq \Omega(\eta_2^i;\omega_i,\phi_i)$ (Marschak and Radner, 1978, p. 65). □

Theorems 4 and 5 together imply the following corollary

Corollary 1:

Given the current information structure η_i, the planner should search for noiseless information structures η_i^* with respect to the given payoff-adequate partition Z_i for the decision situation, of which η_i is a garbling.

Proof. Since η_i^* is a de-garbling of η_i and is noiseless, from Theorems 4 (de-garbling is at least as valuable as garbling) and 5 (noiseless is at least as valuable as noisy), it follows that the partition induced by η_i^* is at least as valuable as that induced by η_i . □

VII. Maximization of Conditional Expected Payoff with Goal Setting

I have introduced rules that tell how the planner could gather information to yield more valuable information structures. In that formulation, the probability density function for states of the grand world, ϕ_i, is given and assumed to be fixed. That is, the noncontrollable variables in the payoff function (2) are ω_i and ϕ_i. In the current section, we treat the probability density function ϕ_i as controllable in form of goals set by the planner as a way to express desired situations. In this case, the expected payoff function (2) can be rewritten as

$$U = \sum_{k=1}^{p} \omega_i \left[x_k^i, \alpha_i(\eta_i \left[x_k^i \right]) \right] \phi_i \left(x_k^i \right) \equiv \Omega\left(\eta_i, \alpha_i, \phi_i; \omega_i\right), \tag{19}$$

where only ω_i is the only remaining noncontrollable variable. Assume the set of probability density functions Φ_i include those functions the planner considered attainable through actions. The planning problem thus becomes one of searching for more valuable information structure η_i such that decision function α_i and probability density function ϕ_i maximize the conditional expected payoff as follows:

$$\hat{\Omega}(\eta_i; \omega_{i,} \phi_i) = \max_{\phi_i \in \Phi_i} \max_{\alpha_i} \Omega(\alpha_i, \eta_i, \phi_i; \omega_i). \tag{20}$$

Choosing a decision function α_i and a probability density function ϕ_i that maximize U in (19) is equivalent to choosing, for each signal y_j^i an action α_i (y_j^i) and a goal $\phi_i(x_k^i)$ that maximize Equation (6). It follows that the action and the goal should be chosen so that the conditional expected payoff given $\eta_i[x_k^i] = y_j^i$ is maximized. The criterion of searching for more valuable information structures as depicted in Corollary 1 applies in this case. Put differently, the distinction of planning with and without goal setting is whether selecting a set of goals in form of probability density functions is incorporated in the model of information searching as depicted in Corollary 1. That is, the planner can simply take the probability density functions of independent random variables as given (without goal setting), or seek the optimal functions (with goal setting) in combination of actions that maximize the planner's expected payoffs.

To illustrate how the model works, consider a land development firm looking for a parcel of land for retailing use in five years. To simplify, the firm considers two location factors: land prices (high or low) and transport networks (convenient or inconvenient) in deciding which land to develop. How should the firm proceed to gather information in order to take the appropriate development action? In this example, combinations of values of location factors are states of the firm's small world. For example, low land price and convenient network is one of the four exhaustive states of the small world. Each state is associated with a probability that in five years that state would be realized. A payoff table can then be constructed specifying under which state which development action would result in how much payoff. Without goal setting, the probability distribution of states is unchanged, whereas with goal setting, the planner should change that distribution, such as higher probability that the location selected is of lower land prices with more convenient transport networks.

Without further information, the problem is a traditional decision problem in that the best action would be the one maximizes expected payoff. What happens if information gathering is possible and how such planning would yield benefit? Following the present model, the firm should first consider all possible information structures, i. e., all possible partitions (or signals) of the four combinations (or states) of the values of the two location factors. Presumably, some partitions have intuitive meanings, insufficient infrastructure is a signal of low land price and inconvenient transport network. There are totally fifteen such partitions. For each partition, the firm is to select the best development action that maximizes payoff, according to Equations (3) through (7). For all the best development actions under different information structures, the firm is then to choose the globally optimal action that maximizes payoff across all the best development actions. The information structure associated with that optimal action should be the one the firm seeks. The above algorithm of exhaustive enumeration does more than what Corollary 1 claims to do, but the underlying logic is the same. The algorithm can best be implemented by a computer rather than by a human alone.

VIII. Discussion

The simplified planning situation described by no means represents the planning contexts in the real world, which may involve several planners and many actors. Planners often encounter information proliferation in making plans; the framework developed here pinpoints a theoretical guideline based on which planning support systems focusing on how information should be gathered can be developed. One might argue that the behavioral model proposed deviates from our daily observations of how planners act, but it forms a basis from which empirical evidence could help make progress for the improved model to reflect human behavior. Similar argument can be found in rationality assumptions of economics (e. g., North, 1996, p. 17). As my illustration shows however, counter-intuitive formulations are useful if they can make problems transparent.

The critical view of this interpretation is that the purpose of planning behavior is to gather information for making contingent decisions that maximizes the conditional expected payoff, and that problems are not solved by plans, but by taking actions based on plans. Hopkins and Schaeffer regard such an interpretation as central to distinguish between three kinds of activities: production of information, regulation, and collective choice (Hopkins and Schaeffer, 1985). They propose a framework incorporating information, rights in land, group formation, and development of built form and use simple examples to provide a coherent framework for describing and interpreting observed planning behavior. They argue that their interpretation implies how planning agencies should organize themselves to effectively carry out plans.

The approach taken here is distinct from Hopkins and Schaeffer's in two ways: (1) My interpretation is normative or deductive in nature, while Hopkins and Schaeffer's empirical and (2) my approach describes explicitly information processing of the planner in making plans. With future effort, the framework can be developed into a more general form for describing normatively how planning should occur between multiple planners and actors.

I suggest two immediate future work and applications following this research: 1) Testing empirically the behavioral validity of the theorems proved and 2) describing planning behavior in real cases. The first would require careful experimental designs in which subjects are required to perform some simple tasks (such as transportation network designs), and their judgments in form of preferences, probabilities, and information structures are recorded to verify whether the criterion of searching for more valuable information as specified in Corollary 1 is satisfied in their planning processes. More specifically, in a gaming context, subjects make observations and decisions as well as sending messages according to some rules of information processing, and planning effectiveness of different organizational structures can be observed. This type of research could alternatively be carried out through computer simulations. The second would require field studies on real planning cases (such as urban renewal cases) and descriptions of planning behavior could be justified in light of the framework provided here.

IX. Conclusions

I have provided an approach to investigating how planning should take place for a unitary organization. In particular, it has been proved that given an information structure of multiple, independent random variables, a best action in combination of goal setting should maximize the conditional expected payoff, and that the planner should search for information structures that are at least as valuable as the information structure available. The case of planning with goal setting in terms of selecting a probability density function for the states in the grand world is interpreted in a similar way. No consideration is given in the current formulation to the cost of information. The logic of planning developed here is based on the criterion of maximizing expected utility. Such normative interpretation of human behavior has been criticized for being unrealistic (e.g. Dawes, 1988). The concepts developed here are thus subject to the same criticism. The proposed explanation of planning behavior can, however, enhance our understanding of how planning should and do take place for a unitary organization. The current formulation can be extended into multiple organizations with conflicting interests in the future.

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