# HUMAN - COMPUTER INTERACTION: AN APPROACH TO DESIGNING MORE EFFECTIVE DECISION-SUPPORT SYSTEMS IN TRANSPORTATION

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## SUMMARY

Many large-scale computer systems are being designed for such transportation applications as automated train control, integrated logistics systems, etc. It is likely that, for the foreseeable future, humans will play major roles in such systems even as substantial portions are automated. To design human-computer systems, a coherent design approach is required, based on explicit analysis of both the human and the computer roles in working on complex tasks.

We present a theoretical framework to be used in designing large-scale human-computer systems. The framework is based on a cognitive model of human problem-solving behavior which has been developed through empirical studies of managers' thought processes. (1)

## OBJECTIVES

Computer applications for complex tasks in transportation have a history of at least 30 years; the first use of transportation models of which we are aware was for the Chicago Area Transportation Study in the early 1950's. Today, we all know of the tremendous advances being made in computer hardware and software; the personal computer, artificial intelligence, user-friendly software are all examples of currently-fashionable innovations. Almost every transportation organization of any size makes some use of computers - at least for such transaction-processing applications as accounting, inventory, and word-processing. Many transportation organizations are almost at the cutting edge of innovative applications; in these organizations, there are transaction processing, management information, decision support system, and even some initial artificial intelligence applications.

The objective of this increasing use of computer power is to enhance the capabilities of the people who work in the organization. Yet, surprisingly, in spite of 30 years' history, we do not have a theoretical framework which can be used as a guide in designing particular computer applications. Just imagine how much more effective our computer systems could be if we really knew what we were doing!

At first glance, the most relevant fields to address this question are artificial intelligence and decision-support systems. However, closer inspection reveals that: artificial intelligence research is oriented almost completely to replacing humans, rather than augmenting their capability.

Furthermore, decision-support systems lack a theoretical core leading practitioners in this field are still exhorting their colleagues to "put" the 'D' back into DSS!"

The basic premise of this paper is that

EFFECTIVE DESIGN OF COMPUTER SUPPORT TO HUMANS REQUIRES AN EXPLICIT THEORY OF HUMAN PROBLEM-SOLVING

We will outline the major elements of such a theory and show by example some of the ways in which this theory can be applied.

Our objective is to enhance the ability of humans to work on complex tasks, through provision of appropriately designed computer support. We believe this point of view is essential to those who are designing Advanced Automatic Train Control (ATC) systems, highly-automated logistics and computer-integrated manufacturing (CIM) systems, systems to support innovative and effective marketing in today's deregulated transportation environment, and other cutting-edge transportation applications.

Why is theory necessary? We see three roles of a relevant theory:

1. Given a planned computer application, we need to know how to design that application so that it will be congruent with the ways humans think and work; otherwise, the system may be unused or misused.

2. Given that one wants to make some particular changes in the ways the organization functions, e.g., the way a particular task is done, a good theory is needed to provide a framework for diagnosing the problem-working processes that people use now in order to identify needed changes, and then to specify the nature of the computer tools to provide to achieve the desired changes in the functioning of the organization.

3. Development of a useful theory may suggest new roles for the computer, which were not previously identified, or even new types of computer systems or software.

## TERMINOLOGY

We will use the term "problem-working" processes in this paper to include all the activities of individuals working on complex tasks. Problem-working is, we think, broader in its implications than the usual terms of "problem-solving" and "decision-making" processes, because much significant human thinking addresses problems without solving them and processes decisions without "making" them.

Further, the empirical research on which we draw is based primarily on studies of senior executives. (3) We think the insights gained there, and the concepts presented here, apply to people at all levels of an organization, so long as the tasks in which they are engaged are sufficiently complex.

## AN EXAMPLE: TRANSPORTATION MARKETING IN A DEREGULATED WORLD

To illustrate the kind of approach we wish to take, consider the problem of providing computer support to enhance the effectiveness of marketing transportation services in today's deregulated, highly-competitive environment (as is typical of freight transportation in the U.S.).

In today's transportation market, there is freedom to innovate in services as well as price. To develop a basis for a proposal to a shipper, the carrier needs to understand the customer's needs as well as, or better than, the customer understands them himself or herself. Ideally, a marketing and sales staff should be able to understand enough about a customer's operations to be able to identify service package possibilities which the customer might not anticipate needing. Identifying such possibilities requires the ability to marshal intelligence from a variety of public and public sources, and the ability to analyze available data in a thoughtful way. It may involve some analysis of the customer's logistics systems and flow patterns, even without access to the customer's data.

Development of a potentially-winning service proposal requires more than analysis; it also requires substantial creativity, imagination, and insight.

Furthermore, developing one or more proposals to the customer is not all that needs to be done; there also is a process of negotiation which must take place, involving numerous cycles of interactions between carrier, salesman and shipper traffic manager or purchasing agent. In addition, both in developing a proposal and in negotiating it, on each side there are multiple parties who must participate.

Identifying possibilities is not enough. The possibilities must be translated into operating plan changes, tested for operational feasibility, costed out, and examined from the perspectives of labor relations, and perhaps other factors. This requires effective interactions between the marketing department and the transportation department, so that they work together in a collaborative, rather than competitive mode, as well as appropriate and timely involvement of other departments such as labor relations, mechanical, car management, etc. (in the railroad case). Further, decisions on what price-service options to offer to the customer are in principle made to maximize profit, rather than to suboptimize on "local" (deparmental or other unit) organizational objectives, but in reality there are almost always multiple and conflicting objectives that enter into the carrier's decision on what service-price package to offer the shipper.

The dynamics of this process, therefore, involve a number of individuals and departments, in both organizations, interacting over time in a complex process of developing, analyzing, and negotiating around complex alternative service-price proposals:

1. the carrier sales and/or marketing people have to develop enough understanding of the customer's likely needs to develop a specific product proposal

2. in order to develop and cost out a specific product proposal, the salesman has to interact with the operations (transportation) department to develop and analyse one or more proposal candidates; interaction with other departments may be necessary before an offer can be made

3. the salesman then presents the proposal (with or without variants) to the customer

4. the customer may need to interact with his user departments and do some analyses before he can determine the desirability of the proposal

5. numerous iterations of the preceding steps may follow

6. the customer and salesman then attempt to negotiate agreement on a proposal

a. each party has an image of the problem, consisting of current understanding of the issues and opportunities, data, inferences about the goals of other participants in both his and the other organization
b. each party has a number of choices open at each step as to what to do next; these choices include:

   i. acquiring more information
   ii. presenting specific information to other parties
   iii. developing new or modified actions
   iv. others

The question we are interested in is this: How can we design information systems support to the carrier sales and marketing personnel for all of this process? From a "rational model" perspective, we would focus on the costing models and perhaps statistical techniques to analyze the shipper's traffic flows. From our perspective, this leaves out several critical areas:

1. the development of an understanding of the critical issues;

2. the creative development of imaginative and effective service and price proposals;

3. the negotiation processes within the carrier organization about what proposal proposal to offer;

4. the negotiation process between the carrier and the shipper.

In many ways, these activities are as critical, or more critical, than the traditional analytical tasks.

Our long-term objective is to develop information systems support to the total process; and to other complex human problem-working processes, in transportation and many other fields. We believe the same types of complexities must be dealt with in computer-integrated manufacturing, automation of logistics systems, air traffic control, advanced automatic train control, and many other problems which today we view as largely traditional modelling problems. To deal with these complexities, we need new theories and methods.

This paper is an initial, tentative exploration of the possible directions for development of appropriate theory. Critical comments are invited.

## THEORIES D, N, AND S

We see the need for three types of theories which together form an integrated theory of computer support to human problem-working:

THEORY D: The first theory element required is a descriptive (D) model of human problem-working processes, one which explains observed behavior.

THEORY N: The second element is a normative (N) model of human problem-working processes; a guide to how humans can work more effectively. The N model should be based on the D model, in that it preserves those elements of human problem-working which are considered unchangeable, intrinsic, or desirable; but it should provide guidance to humans as to how they can be more effective.

THEORY S: The third element is a normative model of how humans and computers can interact productively in a symbiotic (S) manner. By "symbiotic," we mean that humans and computers are mutually interdependent, and the result is more productive and satisfying for humans than working without computer support. (4)

While our basic objective is theory S, we believe such a theory can be most useful if it is derived from, and consistent with, a normative theory of human problem-working (N), which is in turn based on and consistent with a valid descriptive theory (D).

To the extent that there has been theory implicit in past computer applications, that theory has been the "Rational Model" (RM). The RM underlies economic theory (consumer behavior models), operations research and systems analysis, and most computer applications these authors have seen. The RM assumes that individuals formulate their goals in complete, consistent and operational form, search exhaustively among all possible alternative actions, assess the consequences of each action relative to the goals, and choose that action which is "optimal" in terms of those goals.

There is a very large literature which shows that the RM is neither a valid descriptive model of human problem-working behavior, nor a desirable normative model. (3) In the following sections, we describe an alternative model.

## THEORY D: DESCRIBING HUMAN PROBLER-SOLVING

Isenberg has studied problem-working processes of senior managers in a variety of real-world situations. (4) He has identified a number of features of managerial thinking which are elements of a Theory D:

1. senior managers tend to think opportunistically. Managers continually receive information from a wide variety of sources, scan this information to identify opportunities for action, and often take those opportunities as they occur

2. managers manage several overlapping sets of concepts. They manage:

   a. a loose fabric of goals to be achieved
   b. a loose agenda of plans to be implemented
   c. a collection of actions which they are engaged in or considering
   d. a collection of data items and hypotheses or inferences from data

3. the process of understanding involves a number of activities, using a variety of heuristics:

   a. taking action as a means of thinking (as an alternative to extended thinking) (5)
   b. seeking to use limited information effectively
   c. forming generalizations - "plausible inferences" - from a few facts
   d. specifying and providing instances for general ideas, analyses, plans
   e. reasoning by analogy
   f. building and using mental models.

Table 1 gives a list of some of the heuristics used by managers. (A heuristic is any procedure used in problem-solving for which there is no guarantee that it will produce a solution. All human problem-working is heuristic.)

## ELEMENTS OF A DESCRIPTIVE MODEL

We will outline briefly a model of human problem-solving which is useful in explaining the observations of Isenberg (and others). (6)

I. The continuous activities of problem-working: Problem-working is a continuous process, in which the following activities are occurring continuously (7):

A. information acquisition (through the various senses - perceptual, auditory, oldfactory, tactile, kinesthetic);

B. acting (i.e., taking actions in the real, physical world);

C. reasoning, including these activities:

1. planning - developing and modifying agendas of plans
2. goal - setting - developing and modifying a fabric of goals
3. developing understanding -

a. about the problem
b. about the real world
c. about oneself - one's problem-working capabilities and deficiencies, e.g.

II. The divisions of memory: Memory is divided into:

A. working memory (WM) - contains the information which is actively being processed and which guides further processing (i.e., schemas - see below);

B. proximate memory (PM) - portions of memory which are not actively being processed but which either have just been processed or have high probability of being accessed from working memory (i.e., proximate memory is, in some sense, "close" to working memory);

C. long-term memory (LTM) - all other parts of memory.

III. The schematic nature of memory: Memory is composed of chunks of information, called schemas.

A. "A schema is a higher-order knowledge structure that governs behavior in a particular domain or activity, providing a broad abstract structure onto which an exemplar is to be mapper... A schema can be used to organize complex material into constitutents and may be applied recursively to break some of these constituents down further. These same structures also guide the comprehension process by arranging incoming information so that it is structured according to the underlying abstract schema. Absence of an appropriate schema can interfere with both the initial comprehension and subsequent recall of a block of text." (8)

B. There are two basic types of schemas, which are often found

## TABLE 1: SOME HEURISTICS AND THEIR STRUCTURE

1. Major cognitive processes:
   - 1.1 information acquisition
   - 1.2 acting
   - 1.3 reasoning
     - 1.3.1 managing goals - developing, revising goals
     - 1.3.2 managing plans - developing, revising possible actions to implement
     - 1.3.3 developing understanding
2. Managing plans
   - 2.1. idea generation
     - 2.1.1 collect ideas
     - 2.1.2 let ideas hit you
     - 2.1.3 develop ideas without analyzing the problem
     - 2.1.4 consciously work at generating ideas
     - 2.1.5 use structured methods to develop ideas
   - 2.2 action sequencing
     - 2.2.1 plan early steps in detail
     - 2.2.2 leave gaps to re-assess to re-plan; don't overplan
     - 2.2.3 have a rich agenda - too much to do
3. Managing goals
   - 3.1 inferring and modifying goals
     - 3.1.1 discover previously tacit preferences
     - 3.1.2 modify preferences to fit opportunities
     - 3.1.3 modify preferences to fit competencies
   - 3.2 conceptualizing goals
     - 3.2.1 internalize picture of end-state
     - 3.2.2 generalize about goals
4. Developing understanding
   - 4.1 build mental models
     - 4.1.1 recycle between general concepts and specific instances
     - 4.1.2 use available data - infer a lot
   - 4.2 develop procedural knowledge
     - 4.2.1 tacit knowledge
     - 4.2.2 explicit rules of thumb
     - 4.2.3 reflect on your actions in order to learn
   - 4.3 acquire information
     - 4.3.1 passive information collection
     - 4.3.2 set triggers to pay attention, and scan
     - 4.3.3 browse for information
     - 4.3.4 general search for information in a given domain
     - 4.3.5 specific search for missing information, confirmation or disconfirmation of ideas
5. Developing actions
   - 5.1 take action
     - 5.1.1 act as part of learning
     - 5.1.2 act without complete understanding
     - 5.1.3 do easy things right away
     - 5.1.4 take incremental action after assessing risks
     - 5.1.5 combine problems
   - 5.2 avoid action
     - 5.2.1 wait - switch to work on something else
     - 5.2.2 wait - do nothing
     - 5.2.3 avoid decision making if possible

combined together in a third type:

1. template schemas, which provide "a filing system for classifying, retaining, and coordinating incoming data" (9) (e.g., a set of categories into which items are classified)

2. procedural schemas, which provide an action sequence, directing movement and exploratory activities, functioning like a plan

3. mixed schemas, which include both template and procedural elements. Mixed schemas are the most general. We will assume that all schemas are mixed, for generality.

C. Schemas have these major characteristics (10): they "have variables," "can embed one within another," "represent knowledge at all levels of abstraction," "represent knowledge rather than definitions," "are active processes," and "are recognition devices whose processing is aimed at the evaluation of the goodness of fit to the data being processed." "Our schemata are our knowledge. All of our generic knowledge is embedded in schemata."

D. There are a number of examples of schemas which are particularly important from our point of view:

1. schemas providing structure for such major concepts as goals, plans, actions, data, inferences, and other elements;

2. schemas providing processes such as:

   a. managing goals
   b. managing actions
   c. developing understanding
   d. and others of the heuristics managers have been observed to use (Table 1, e.g.)

IV. The network structure of schemas in memory: Schemas can be visualized as nodes in a network of concepts, and there exist many types of relations between these concepts, which can be visualized as links in the network.

A. The network is hierarchical, in that higher-level schemas include one or more lower-level schemas, where "include" denotes relationships such as

1. means of achieving
2. component of
3. more detailed specification of
4. others

B. There are many other types of relationships among schemas in memory.

V. Activation processes: Thinking - "working on a problem" - occurs by the activation of one or more schemas, by bringing those schemas "into" working memory, and moving some or all of previous schemas out of working memory into proximate or long-term memory.

VI. Control logic: The continuing processes of information acquisition

(IA), action (A), and reasoning (R) are guided by a control logic with these characteristics:

A. the program operates at several levels:

1. at the highest level, the basic decision is whether to continue the present processing activities or to change some aspect(s) of current activities (IA, A, R)

2. at lower levels, decisions are made about which heuristics to execute and/or how to process incoming information

B. schemas play a major role in the control process:

1. the control program controls the selection of schemas, i.e., establishes priorities over:

a. current working schemas - schemas currently activated which are directing (IA, TH, A)
b. shift of activated schemas - activating schemas in proximate memory (moving them "into" working memory); moving activated schemas into proximate memory and possibly long-term memory; moving schemas from LTM to proximate memory and possibly to working memory
c. triggers - sets up "triggers" in memory which monitor incoming information, and when appropriate conditions are encountered, activates corresponding schemas

1) trigger schemas set up triggers, specify which schema(s) to activate when trigger is activated
2) triggers are probably in proximate memory, neither activated into working memory nor far away in long-term memory
3) control program monitors incoming Information Acquisition stream and activates specific triggers when appropriate
4) activation of trigger activates corresponding schemas and shifts processing to those schemas
5) control program addresses priority conflicts among conflicting triggers, i.e. conflicting schemas "wanting" to be activated

2. schemas are important inputs to the control program, in that the control decisions are influenced by:

a) the current products of (IA, A, R), which flow into new or previous schemas in working memory
b) currently-activated schemas, in working memory, directly, or indirectly, when activated schemas or triggers activate other schemas in proximate or long-term memory; the newly-activated schemas may replace the present ones and influence the control decisions

VII. Learning and skill acquisition: Learning involves:

A. the addition of new schemas, at "higher" or "lower" levels of operationalization (e.g., one might speculate that concept formulation involves constructing higher-level schemas, while skill acquisition involves detailing of lower level-schemas), and

B. the addition of new "links" to the network, representing new associations

C. a number of different dimensions

1. about goals and about the actions which can potentially achieve the goals (11)
2. about competencies - what the individual can do - as well as about wants - what the individual wants to do
3. about the problem at hand;

a. about the process of working on the problem;
b. about the real world

VIII. The "messy reality" of the process: The process is undoubtedly more complex than this simple outline:

A. parallel processes operate

B. networks of schemas form loose hierarchies, with overlap and repetition (semi-lattices, not trees)

C. the process is not deterministic but probabilistic: schema activation is probabilistic; relationships among schema are probably also probabilistic

D. there are many conflicts to be resolved in the control process:

1. agendas may have conflicting goals which are not yet clarified
2. actions overlap
3. triggers compete for attention

To summarize: there are several key elements which link this abstract model to Isenberg's empirical observations:

1. The heuristic observed are reflected in procedural or mixed schemas, and the conceptual elements (e.g., goals, plans) in template or mixed schemas.

2. Opportunity thinking is reflected in the scanning of incoming information, from information acquisition or reasoning, under the guidance of currently-activated schemas in working memory and triggers in proximate memory. The results of this scanning influence what is activated next.

**THEORY N: A NORMATIVE THEORY**

Isenberg's empirical work suggests some elements of a normative theory.

Compare the assets and liabilities of the opportunism approach. In a purely opportunistic approach, an individual responds to each opportunity as if arises, and accepts or rejects it:

> "Opportunistic thinking is manifest in the manager's response to the immediate stimuli, information, or ideas that are currently available to the manager at little or no extra 'cost' (in terms of time, money, or other resources)...."

> "A manager is opportunistic when he or she uses intuition, takes action without regard to the longer term implications, makes guesses, inferences, and hunches based on available information, or takes advantage of unanticipated opportunities in any way. The manager who is opportunistic takes actions that may be inconsistent with his or her overall plan or priorities... . Intuition is a type of opportunistic thinking because it is a judgement based on immediately (intuitively) available ideas, ideas that pop into mind." (12)

We can contrast opportunism with a strategic, or rational model-like, approach:

> "Strategic thinking is manifest in the manager's ability to cast his or her immediate objectives, plans, and actions in (terms of longer range missions, goals, and values... ."

> "Strategic thinking is thinking that takes the manager's overall situation into account in choosing a course of action. The manager who thinks strategically is looking beyond the immediate pressures and rewards of the present, to the longer term. Strategic thinking, therefore, guides the tradeoffs that managers make between short run and long run goals. ... (S)trategic thinking also includes the thought processes that managers use to form their image of the 'big picture,' their ultimate values, and their overarching plans." (13)

A pure strategic approach involves substantial time and other resource expenditures, to formulate coherent long-range goals, to develop and analyse alternative long-range plans, to develop and analyse alternative sequences of step-by-step actions to implement the long-range plans, and so forth. The weakness of the strategic approach is that, like the rational model approach, it demands great resources and effort for a wide-ranging, systematic process, and defers decisions or action until the process is completed.

A pure opportunistic approach, on the other hand, involves making decisions from a very short-term perspective, which, while exploiting continually-changing opportunities as they arise, may often result in failure to achieve long-range goals.

According to Isenberg, "the bulk of evidence is that senior managers use a blend of opportunistic and strategic thinking, somewhat weighted in the opportunistic direction." (14) Isenberg terms this mixed approach "strategic opportunism." Essentially, a manager operating with a strategic opportunism approach is trying to keep the advantages of both while reducing the disadvantages of each.

According to Theory D, managers operate with a large vocabulary of heuristics in a largely, but not completely, opportunistic way. Guiding this process there must be a "control logic" of some type. This control logic selects which heuristic to use, when, as the manager works.

We hypothesize that one element of this control logic is reflected in the choice of being opportunistic or strategic in approach. We see a spectrum of approaches, ranging from opportunism at one end to strategic at the other; the control logic determines where along this spectrum to be at any instant. Strategic opportunism, then, is a middle ground along this spectrum.

A key element of a normative model is that the decision of which heuristic to use next is guided by a strategic opportunism approach. In this approach, there are several major elements:

1. current data: a set of goals, a set of plans, a set of actions for implementation, current inferences and hypotheses, etc.

2. a continuing inflow of information

3. a process of scanning information to identify opportunities

4. a control logic which

   a. assesses opportunities relative to current goals and plans
   b. selects actions to advance goals and plans, or to develop understanding
   c. continually strives for a strategic/opportunistic balance, depending upon current issues and opportunities.

Strategic opportunism is a more general model than Simon's satisficing. (15) The essential logic of strategic opportunism is that there is a control process over the thinking process, the problem to be solved is how best to allocate problem-working effort. The general logic for making this decision is, in principle, to consider the various cognitive procedures that might be activated next, assess the advantages and disadvantages of each, and choose to do next that cognitive activity which has the greatest return. (16) In actuality, of course, the actual logic is unlikely to be so systematic.

Nevertheless, the consequence of this model is that decisions about where to be on the spectrum between opportunism and strategic thinking are made in the context of the moment; and in general, the optimum balance is the mixed strategy in the middle.

Thus, we hypothesize that the most effective strategy for management problem-working is strategic opportunism; opportunism tempered by strategic views of goals and plans, and effective use of thinking by acting and other heuristics to develop understanding.

## ELEMENTS OF A NORMATIVE MODEL

Our discussion of the descriptive model left open the nature of the control logic. One effective control logic is the strategic opportunism model. However, this may not always be appropriate: there are many situations in which a highly-opportunistic strategy is effective, and some situations in which a more systematic, "rational model," type of approach may be warranted.

IX. Explicit strategic opportunism control strategy: Use of strategic opportunism as a control strategy guiding activation of schemas into working memory.

   A. Depending upon currently-activated schemas, including goals, plans, etc.; triggers and other schemas in proximate memory; the content of information acquisition; and other elements; the decision process about what to activate next is guided by current strategy.

   B. Current strategy varies along the spectrum between opportunism and strategic thinking as a function of these same elements.

## THEORY S: NORMATIVE - SYMBIOTIC RELATIONSHIP OF HUMAN AND COMPUTER

Our objective is to provide computer support which enhances the natural problem-working processes of the user, and does not force the user into unnatural modes except under certain special conditions.

The first task in doing this is to formulate an explicit theoretical model of human problem-working, which is a valid descriptive model and which is explicit in its normative elements. This we have done, in a preliminary and tentative way, in the preceding sections.

The second task is to build on this problem-working process model and specify the key design features of a computer support environment. We propose these features:

1. explicit representation in the computer of the user's conceptual structure, as a network of schemas

2. explicit provision of support tools which enhance the user's natural problem-working style, by supporting observed heuristics and providing conventional tools as well:

    a. fabrics of goals, plans, and actions
    b. patterns of understanding
    c. use of a variety of heuristics
    d. inclusion in heuristics of some uses of systematic methods

3. explicit provision of conventional rational model tools, linked to schematic network and heuristics as well as data

4. provision of control capabilities which enhance the user's ability to balance strategic and opportunistic thinking in a style of "strategic opportunism."

## APPLYING THEORY S: USING EXPLICIT SCHEMATIC NETWORKS TO PROVIDE COMPUTER ASSISTANCE TO HUMAN PROBLEM-SOLVING

We will now amplify on these points by illustrating some of the types of capabilities to be provided in a computer support system.

1. Explicit representation of human schematic network in computer: The premise is that it is very useful to have in the computer at all times a representation of the user's cognitive knwoledge, in the form of a schematic network. This is the basic "data base" of the problem-working process, and access to it can be very useful for both user and computer processing. (17)

    a. This data would be input in various ways:
        i. user inputs data explicitly
            (1) in a structured way: "Here is a list of my current goals; and here is a list of the key people in the shipper's organization who may influence the purchase decision. Here are three alternative price-service packages which we are considering."
            (2) in a loose, stream-of-consciousness manner: "give a price incentive if they clean the cars," "10% penalty if they fail to release cars within four hours,"

"opposed by their finance guy," "maybe purchasing agent can influence financing," etc.

(3) initially loose, then modified and structured; user goes back over "loose" input, and orders it in various ways - for example, point to a phrase and identify it as a statement of a goal, or a statement of a possible action; this would work somewhat like the use of "Outliner" software on micros to generate a logical outline for a report before actually writing it; for example, the user reviews loose input in one window and formulates in additional windows lists of goals, lists of possible plans, lists of possible actions, etc.

ii. system makes inferences about user's schematic network:

(1) For example, carrier decides to propose a high-cost service option ($45,00 per ton) with no requirement for car cleaning by shipper; over a lower price ($40.00) with a car cleaning requirement. Computer system then infers that carrier cleaning of car is less than $5.00 per ton.

(2) Within a few years, it should be possible to have routines which scan loose text and infer elements of a schematic network.

b. direct uses of the explicit network:

i. notepad function: important concepts are available for later retrieval - the network is important in and of itself; a notepad function allows retrieval of the material later to aid recall

ii. stimulus function: user can stimulate development of new ideas by various recall and display options; e.g., user review of input material as "brainstorming" stimulus; use of outliner or similar tools (18)

iii. inference function - computer procedures can make inferences which extend the network - add links (connections between concepts) and even nodes (new concepts), or exploit the inferences to bring new ideas up to human for considerations.

2. Explicit provision of tools supporting observed heuristics, using the schematic network for portions of input and/or output

a. example: managing a loose set of plans;

i. user reviews network, identifies certain concepts as possible plans and assigns them "plan" labels,

ii. in the process, user is stimulated to formulate a number of additional plans and inputs them

iii. system creates a file of plans; user edits file, designates some plans to be discarded, indicates others to be maintained actively; identifies various relationships among plans (inclusion, specification, precedence, alternatives)

iv. user selects some plans and explicitly prioritizes and sequences them; these become his "current priority plans" file.

b. example: managing a loose fabric of goals;

i. user reviews network, identifies certain concepts as statements of goals and assigns them "goal" labels

ii. in the process, user is stimulated to revise and refine goals, and inputs new and changed statements of goals

iii. user edits file of goals, making decisions about which goals are means to higher-order goals, which goals are alternatives or in conflict, which are high priority, which near-term, and other constructs useful in structuring a loose set of goals (e.g., the "goal fabric" construct of Manheim and Hall (19)

c. example: evaluating alternative plans
   i. user focusses on choosing among certain plans, by:
      (1) designating subset of plans
      (2) designating subset of goals relevant to those plans
      (3) reviewing consequence data associated with selected subset of plans
   ii. where necessary, user adds more consequence information to plans, by judgement, by using mental modelling heuristics, and/or by using formal models to predict consequences.
   iii. user evaluates plans, using one or more heuristics
      (1) assessment of the arguments for and against a plan by listing the advantages in one column and the disadvantages in a second, and crossing off advantages and disadvantages which roughly cancel out
      (2) pairwise comparison of consequences, two plans at a time, looking for dominance relations or tradeoffs, and referring to relevant goals as needed
      (3) ranking plans by various consequences relative to goals, in style of, "from the perspective of this goal, which plans are best?"
      (4) using other heuristics
      (5) using various systematic techniques, such as linear scoring functions, economic criteria (e.g., maximize profit, rate of return on investment), or more general utility functions (e.g., multi-attribute utility, decision analysis) (20)
   iv. in the process, iterating to (i) and (ii) as ideas occur

d. example: use the heuristic "avoid action - wait, switch to work on something else" (Table 1):
   i. don't do anything further about it for a while
   ii. let the computer work on it while the user does something else: formulate the problem for computer processing, then the computer keeps working on the problem
   iii. computer occasionally pokes something up for user to review and react to
      (1) e.g., user put some comments in notepad,
      (2) user modify formulation of problem to computer processing, and/or
      (3) user stop work on other tasks and shift back to this activity

e. example: use the negotiation heuristic "search for an integrative solution," where an integrative solution is one which makes both parties better off -a "win-win" solution. To support this heuristic, use Alexander's method for guiding a human's process of inventing good solutions to a complex problem. (21)
   i. computer scans schematic network and pulls out:
      (1) the user's own goals - e.g., what the salesman feels are his and his organization's goals
      (2) the user's beliefs about the other party's goals - e.g., what the salesman believes are the goals (needs,

requirements, concerns) of the shipper's purchasing agent or traffic manager, and other critical individuals in the shipper's organization

ii. user reviews goals, eliminates some, adds new ones, and identifies which pairs of goals conflict

iii. computer routine, based on Alexander's method, analyses the pattern of conflicts among the goals and produces a decomposition - a tree of subsets of goals, defining a hierarchy of subproblems

iv. user develops one or more integrative solutions using decomposition as a guide

v. the developed candidate solutions are added to the current set of actions (22)

3. Explicit provision of conventional rational model tools, artificial intelligence modules such as expert systems, etc. (33)

a. examples: linear programming, other organization models; specific simulation models; costing models; small expert systems; simple causal models

b. tied to schematic network, in that concepts in network point to data files which

i. contain input data

ii. specify models or modules to be used

iii. provide structure for output data files

iv. provide structure for logging each formal analysis in to overall "history" of analysis process to allow for future recall

c. tied to schematic network in that the "notepad" provides support for the user to input concepts as he or she selects a model(s), uses it, and examines the output: for example, look at output and remark, "this price-service proposal does pretty well on rate of return and capturing a big share of this shipper's business, but I wonder whether the work rule changes will disrupt labor relations?"

4. Explicit provision of support to range of problem-solving strategies: The system provides a number of features to support a range of strategies:

a. information input is scanned by "monitor" schemas, which initiate particular actions when they are triggered.

b. current goals, and current plans, are scanned and displayed together with articulated long-term goals to stimulate the user to assess their consistency or inconsistency

c. the system provides tools to support a range of variations between opportunism and strategic thinking (including some rational model tools)

## CONCLUSIONS

In this paper, we have identified a need for a new approach to designing computer support for applications in transportation and other fields. We outlined one possible approach to meeting this need, drawing on recent theoretical and empirical work.

We apologize to the reader for the abstraction of this presentation. In our continuing research on this topic, we will be developing example applications of these concepts, further developing and testing the theory, and developing software tools to operationalize and test these ideas in practice. We would look forward to discussion with others, and case problems to which these concepts might be applied.

**NOTES**

1. We acknowledge many fruitful discussions with Prof. Max Bazerman, Cy Olsen, Mark Moore, and especially Prof. Reid Hastie. The authors alone are responsible for the content of this paper.

2. C.S. Stabell, "A decision-oriented approach to building DSS," in J.L. Bennett, editor, BUILDING DECISION SUPPORT SYSTEMS, Reading, Mass.: Addison-Wesley, 1983.

3. D.J. Isenberg, "The Structure and Process of Understanding: Implications for Managerial Action," in H. Sims and D. Gioia, editors, THE THINKING ORGANIZATION, San Francisco: Jossey-Bass (1986), pp. 238-262; D.J. Isenberg, "Thinking and Managing: A Verbal Protocol Analysis of Managerial Problem-Solving," ACADEMY OF MANAGEMENT JOURNAL (in press).

4. "Symbiosis" is from the Greek symbioun, to live together; its dictionary meanings are: "1. Biology: the intimate living together of two kinds of organisms, esp. where such association is of mutual advantage ... 2. a similar relationship of mutual interdependence between persons and groups." WEBSTER'S NEW WORLD DICTIONARY OF THE AMERICAN LANGUAGE. Second College Edition, New York: Simon and Schuster (1982), p. 1442.

5. There is a substantial literature of criticism of the Rational Model. See for example Simon on "satisficing," Lindbloom on "disjointed incrementalism," M.L. Manheim's "PSP" model; and D.J. Isenberg: H. Simon, 1977, THE NEW SCIENCE OF MANAGEMENT DECISION, Englewood Cliffs, N.J.: Prentice-Hall; D. Braybrooke and C.E. Lindblom, 1963, A STRATEGY OF DECISION, Glencoe, Ill.: Free Press; M.L. Manheim, 1969, "Search and Choice in Transport Systems Analysis," HIGHWAY RESEARCH RECORD, 293, 54-82; D.J. Isenberg, "Strategic Opportunism: Managing Under Uncertainty," working paper.

6. D.J. Isenberg, "Thinking and Managing: A Verbal Protocol Analysis of Managerial Problem Solving," ACADEMY OF MANAGEMENT JOURNAL (in press); D.J. Isenberg, "Strategic Opportunism: Managing Under Uncertainty," working paper; D.J. Isenberg, "How Senior Managers Think," HARVARD BUSINESS REVIEW, 6:80-90; DJ. Isenberg, in Sims and Gioia, loc. cit.

7. D.J. Isenberg, "Strategic Opportunism ...," Op. Cit.

8. Loc. cit.

9. D.J. Isenberg, "Search and Choice ...", Op. Cit.

10. M.L. Manheim, "Search and Choice ... ". Op. Cit.

11. D.J. Isenberg, in Sims and Gioia, Op. Cit.

12. D.J. Isenberg, "Thinking and Managing ...," Op. Cit.

13. Loc. cit.

14. The model described here is an amalgam of concepts in cognitive psychology, artificial intelligence, decision support systems, and the authors' own theoretical work. We have not tried to cite each detailed source for each element of the model. Generally-useful material in this literature include: J.R. Anderson, 1980, COGNITIVE PSYCHOLOGY AND ITS IMPLICATIONS, San Francisco: W.H. Freeman; J.R. Anderson, ed., 1981, COGNITIVE SKILLS AND THEIR ACQUISITION, Hillsdale, N.J.: Erlbaum Associates; S.K. Card, T.P. Moran, and A. Newell, 1983, THE PSYCHOLOGY OF HUMAN-COMPUTER INTERACTION, Hillsdale, N.J.: Erlbaum Associates; N. Pennington and R. Hastie, 1985, CAUSAL REASONING IN DECISION-MAKING, Unpublished working paper, Department of Psychology, Northwestern University. See also following notes on schemas and on networks.

15. See for example: S.K. Card, T.P. Moran, and A. Newell, Op. Cit.

16. R. Jeffries, A.A. Turner, P.G. Polson, and M.E. Atwood, 1981, "The Processes Involved in Designing Software," in J. R. Anderson, (ed.), COGNITIVE SKILLS AND THEIR ACQUISITION, Hillsdale, N.J.: Erlbaum Associates.

17. R. Hastie, 1981, "Schematic principles in human memory," in E.T. Higgins, C.P. Herman, and M.P. Zanna (eds.), SOCIAL COGNITION: THE ONTARIO SYMPOSIUM ON PERSONALITY AND SOCIAL PSYCHOLOGY, Hillsdale, N.J.: Erlbaum Associates, 39-88.

18. D.E. Rumelhart, 1985, "Schemata and the cognitive system," in R.S. Wyer and J.K. Srull (eds.), HANDBOOK OF SOCIAL COGNITION, Hillsdale, N.J.: Erlbaum Associates, 161-188.

19. M.L. Manheim, 1969, "Search and choice ...," Op. Cit.

20. D.J. Isenberg, "Strategic Opportunism," p. 27.

21. D.J. Isenberg, "Strategic Opportunism," p. 25-26.

22. D.J. Isenberg, "Strategic Opportunism," p. 27

23. H.A. Simon, Op. Cit.

24. An early model for making this type of process decision explicitly was developed by M.L. Manheim, HIERARCHICAL STRUCTURE: A MODEL OF PLANNING AND DESIGN PROCESSES, Cambridge, Mass.: M.I.T. Press (1966).

25. The field of "knowledge representation" is concerned with various techniques for representing human knowledge in a form which can be operated upon, generally for simulation of cognitive processes or for artificial intelligence models which attempt to solve particular problems in lieu of a human (e.g., language translation). The schematic network is one form of representation which we believe will be useful in the context of computer support to human problem-working processes. For general references: R.J. Brachman and H.J. Levesque, (eds.), 1985, READINGS IN KNOWLEDGE REPRESENTATION, Los Altos, CA.: Morgan Jaufmann; M.L. Brodie, J. Mylopoulos, and J.W. Schmidt, (eds.), 1984, ON CONCEPTUAL MODELLING, New York: Springer Verlag; D.R. Dolk and B.R. Konsynski, 1984, "Knowledge Representation for

Model Management Systems," IEEE TRANSACTIONS ON SOFTWARE ENGINEERING, Vol. SE-10, No. 6, (Nov.).

26. M.L. Manheim, 1986, "Creativity support systems for planning, design, and decision support," MICROCOMPUTERS IN CIVIL ENGINEERING, (forthcoming); L.F. Young, 1985, "Idea Processing Systems: Definition, Concepts and Initial Applications," DSS-85 TRANSACTIONS, Providence, R.I.: The Institute of Management Sciences, 125-134.

27. M.L. Manheim and F.L. Hall, 1968, "Abstract Representation of Goals: A Method for Making Decisions in Complex Problems," in TRANSPORTATION: A SERVICE, Proceedings of the New York Academy of Science, New York, New York: New York Academy of Science, 731-740.

28. See for example: M.L. Manheim, 1979, FUNDAMENTALS OF TRANSPORTATION SYSTEMS ANALYSIS, Vol. I, Cambridge, Mass.: M.I.T. Press, Chapter 9.

29. C.W.J. Alexander, 1962, NOTES ON THE SYNTHESIS OF FORM, Cambridge, Mass.: Harvard University Press; C.W.J. Alexander and M.L. Manheim, 1962, "The Design of Highway Interchanges: An Example of a General Method for Analysing Engineering Design Problems", HIGHWAY RESEARCH RECORD 83, Washington, D.C.: Highway Research Board, 43-87.

30. We are experimenting with this approach by putting these capabilities in AE-1, a microcomputer software shell for use in managing libraries of modules.

31. See for example, D.R. Dolk and B.R. Konsynski, _Op. Cit._; J. Fedorowicz and M.L. Manheim, 1986, "A Framework _for Assessing_ Decision Support Systems and Expert Systems," in J. Fedorowicz, editor, PROCEEDINGS OF DSS-86 SIXTH INTERNATIONAL SYMPOSIUM ON DECISION SUPPORT SYSTEMS, Providence, R.I.: Institute of Management Sciences.