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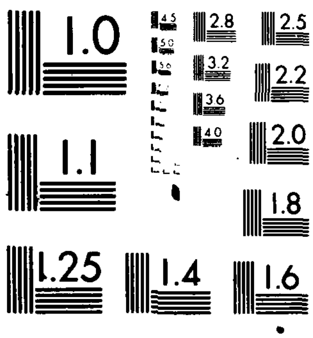

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PLANNERS' WORKBENCH: A COMPUTER AID TO RE-PLANNING

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PREFACE

This paper reports the current status of a computer aid to re-planning, the PLANNERS' WORKBENCH. Current organizational planning methods support the generation of large, complex configurations of planned activities. However, they do not provide mechanisms for modifiying plans in the face of changed assumptions or new environmental conditions. The PLANNERS' WORKBENCH would fill this need by recording the considerations made during plan generation--the plan rationale--and providing facilities for exploiting the rationale during re-planning.

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I. INTRODUCTION

Re-planning is a crucial component of effective organizational behavior. Organizations plan actions to cope with or exploit anticipated future conditions. However, they typically cannot predict all relevant conditions and must modify their plans as circumstances require. Given the size and complexity of most organizational plans, re-planning is a major undertaking. It is difficult to determine which components of a plan are affected by changed circumstances, what alternatives are available, and how these alternatives would interact with other plan components. Further, organizations frequently must re-plan under crisis conditions. There is little time to spare researching these questions

Ideally, re-planning would benefit from the rationale underlying the original plan. The rationale includes all of the data, assumptions, and arguments considered during the original planning activities. It could suggest answers to the re-planning problem or constrain the organization's approach to it. Unfortunately, this rarely happens because there is no currently available technology for recording and using plan rationales. As a consequence, re-planning often means abandoning the original plan and beginning anew. Hence, re-planning tends to be slow, costly, and inefficient.

We are developing a computer system to support re-planning, the PLANNERS' WORKBENCH. Our work builds on previous AI systems that model the planning process and represent final plans (see Section 3). It goes beyond the earlier work to identify and represent the rationale components underlying final plans and to make these components useful during the re-planning process. The developing system will also incorporate a variety of other AI methods and computer science technologies (see Section 4).

The remainder of the paper is organized as follows. Section 2 presents a simple example of the re-planning problem and illustrates how a re-planning system might facilitate the process. Section 3 presents the design goals of the PLANNERS' WORKBENCH and describes current implementations of some of its features. Section 4 discusses future research directions.

II. THE RE-PLANNING PROBLEM

To motivate the discussion and illustrate the issues, we introduce a much over-simplified organizational planning problem. Suppose you are a dispatcher for a large-scale equipment company, the Whole Earth Moving Company (WEMCO). Your function is to assign previously planned routes to equipment operators each morning. Because it is extremely expensive to move WEMCO equipment and because the catalogued plans are sometimes out of date, you carefully review each plan before assigning it. You verify that the plan prescribes valid routes for moving the equipment to a given destination and that the prescribed routes are efficient under present conditions.

One Friday morning you arrive at work and are tasked to move a bulldozer from WEMCO's home base in Santa Monica to the intersection of Topanga Canyon Road and Ventura Boulevard in the San Fernando Valley. Your catalogued plan for this destination is:

> Take the coastal route unless school is out and it is
> a sunny day; in that case, take the inland route.

(See Figure 1.) You also know that a presidential motorcade will be traveling up the Pacific Coast Highway from the Los Angeles Airport to Santa Barbara sometime this morning. In fact, President and Mrs. Reagan plan to spend most weekends at the Santa Barbara ranch and, since they enjoy the view, traveling up the Coast Highway on Friday mornings has become a weekly ritual for them.

Before issuing the catalogued plan to an operator, you must determine whether the presidential motorcade will impede its

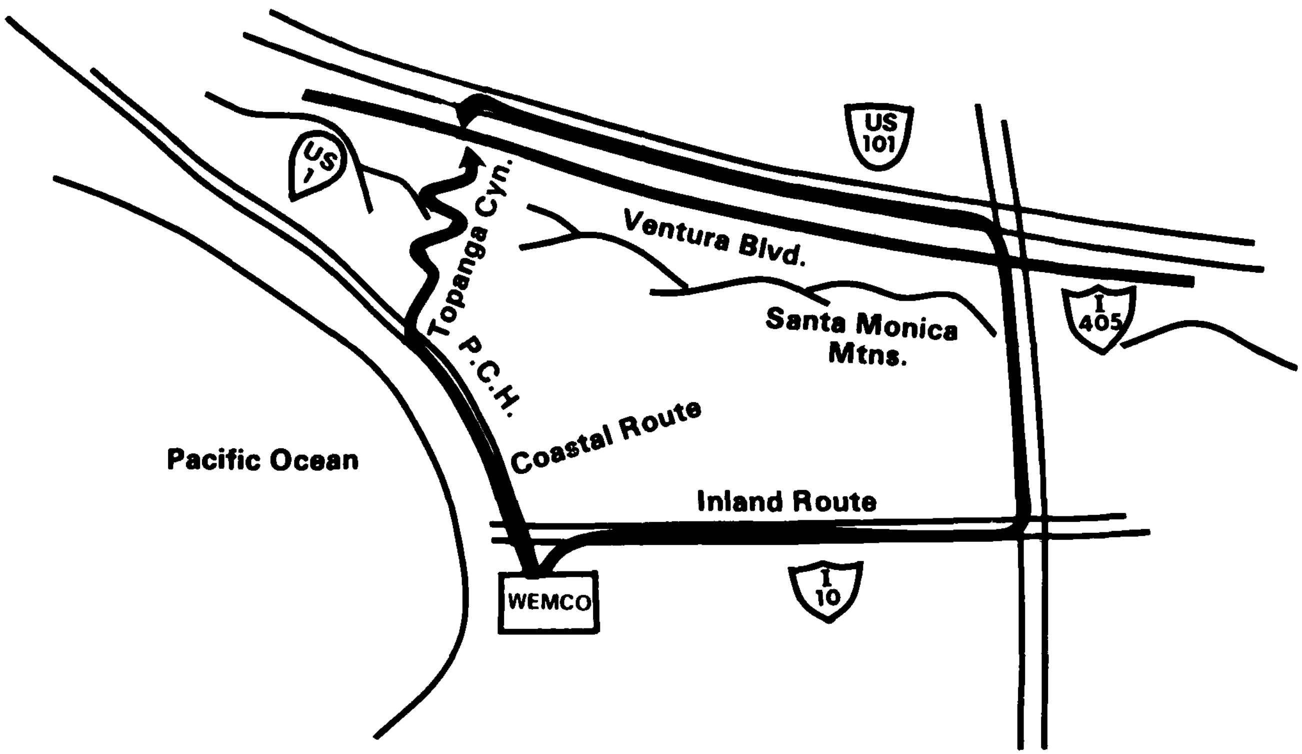

Fig. 1--Plan for moving equipment from WEMCO to the intersection of Topanga Canyon Road and Ventura Boulevard.

effectiveness. If it does, you must update the plan. Here are some of the questions you must answer: In what way is the current plan sensitive to presidential motorcades? Does the motorcade violate any of the assumptions underlying the plan, conflict with any of its goals, or usurp any of its resources? What alternatives are available if the planned actions are no longer effective? What considerations should determine the selection among alternative actions?

Because the catalogued plan does not specify contingencies for presidential motorcades per se, it provides no direction for the re-planning process. Because you did not formulate the original plan, you have no direct knowledge of its assumptions or constraints. Therefore, you must either rely on your own intuitive capacities to evaluate and modify the catalogued plan or simply abandon it and develop a new plan from scratch, taking the motorcade into account.

As this simple example illustrates, re-planning rarely benefits from its formal and semantic similarities to the original planning process. This is because planners generally preserve only the terminal decisions of the planning process, the plan itself. They discard the rationale underlying the plan--the information that would prove most useful during re-planning.

Suppose, for example, you could re-examine the rationale underlying the catalogued Topanga-Ventura plan. It might have evolved in a conversation like the following one between two planners:

Smith: OK, let's start with the Topanga-Ventura plan.
Jones: We've got two choices for that one, the coastal route or the inland route.
Smith: Which is the most efficient?
Jones: The coastal route. It's the shortest. Shorter routes are

faster and time is the principal cost component.

Smith: True, except under unusual circumstances, say if there were heavy traffic on the Pacific Coast Highway. You know, people going to the beach. When it's a sunny day and the kids are out of school, people head for the beach. It makes a mess of the Coast Highway.

Jones: OK. So we'll take the Coast Highway unless it's a sunny day and the kids are out of school. That should get the equipment there efficiently and minimize cost.

The above conversation reveals the following propositions: (a) prefer the coastal route over the inland route if it is the most efficient route to the Topanga-Ventura intersection; otherwise prefer the inland route; (b) the coastal route is the most efficient route when usual traffic conditions exist on the Pacific Coast Highway; (c) people traveling to the beach produce unusually heavy traffic on the Pacific Coast Highway; and (d) when school is out and it is a sunny day, people travel to the beach. Notice that, while all of these propositions are necessary to _justify_ the original catalogued plan, only parts of (a) and (d) actually appear in the plan.

While the plan itself does not help you to re-plan routes to the Topanga-Ventura intersection, the rationale underlying the plan does. Propositions (a) and (b) indicate that the coastal route is preferred only when usual traffic conditions obtain on the Pacific Coast Highway. You know from experience that celebrity motorcades on the Pacific Coast Highway invariably produce heavy traffic. President Reagan's motorcade probably will do the same. Proposition (c) indicates that people going to the beach alter traffic conditions, but there are no propositions regarding the effects of celebrity or presidential motorcades. Hence, you conclude that the rationale is incomplete. It should also include propositions (e) celebrity motorcades produce unusually heavy traffic on the Pacific Coast Highway, and (f) there will be presidential motorcades on Friday mornings.

Working with the revised rationale, you reconsider the catalogued plan. The rationale indicates day of the week as an important parameter. The plan, however, does not. Therefore, you modify the plan as follows:

> Take the coastal route unless (a) school is out and it is a sunny day, or (b) it is Friday; in either of these cases, take the inland route.

This simple example only hints at the potential advantages of exploiting plan rationales during re-planning. If you are a clever dispatcher and familiar with the coastal route, you might infer from the plan itself that traffic conditions are a major consideration. In that case, you would have no trouble modifying the plan to accommodate presidential motorcades. However, most organizational plans are extensive. They take weeks, months, or longer to prepare and they express complex relationships among many assumptions, parameters, actions, and goals. They reflect inputs from a variety of individuals and exogenous information sources such as memos, empirical studies, and simulations. Finally, the people who are responsible for re-planning typically are not the people who formulated the original plan; they are unfamiliar with the plan and its genesis. Thus, the re-planning problems we wish to address are of far greater magnitude than those illustrated in this example and would benefit enormously from the kind of assistance we propose.

In addition, the example illustrates only three of the many useful functions plan rationales can support. First, the organization can review the considerations and arguments used during plan development. In this example, you review the plan for information related to presidential motorcades. Second, the organization can update the rationale or the plan. In this example, you update the rationale to incorporate the new assumptions regarding presidential motorcades. Third, the organization can justify the plan in terms of its underlying assumptions. In this example, you justify the original plan in light of the new rationale components, determine that it needs modification, and update the plan accordingly. In the next section, we discuss other functions the PLANNERS' WORKBENCH might perform and demonstrate some of them with our two working systems, DEMO and WAND.

III. DESIGN GOALS AND CURRENT IMPLEMENTATIONS

To date, AI has produced several planning methods, but none of them is very useful for re-planning. Like human planners, AI planning systems focus on producing the terminal nodes of a planning tree--the plan,--rather than on explicating and recording the intermediate decisions and dependencies--the plan rationale. Several systems generate goal trees during planning (e.g., Fahlman, 1974; Fikes, 1977; Sacerdoti, 1974, 1975; Stallman & Sussman, 1977). Hayes-Roth, et. al. (1979) also note the heuristics and data support plan components. While these kinds of information are useful elements of the plan rationale, many other kinds of information are necessary to support efficient re-planning. None of the previous systems provides facilities for searching, analyzing, or otherwise using plan rationales during re-planning. Accordingly, this section outlines our design goals for the PLANNERS' WORKBENCH: the components and structure of plan rationales and system facilities for exploiting plan rationales.

PLAN RATIONALES

A plan rationale should contain all of the considerations made during plan generation, including the following:

(1) Goals. The rationale should indicate what goals the organization has decided to pursue and what goals it has rejected. These should include both objectives to be achieved (e.g., move the equipment to the intersection of Topanga and Ventura) and general policies or constraints to be satisfied along the way (e.g., minimize

cost).

(2) Candidate Plan Components. The rationale should indicate what plan components the organization has decided upon and what components it has rejected. These should include actions (e.g., take the coastal route), resources (e.g., requires forty-five minutes), and parameters (e.g., if today is Friday).

(3) Inputs to the Planning Process. The rationale should describe inputs that have influenced the planning process and those that have been explicitly rejected. These include data (e.g., the coastal route is 17 miles long), assumptions (e.g., longer routes take longer to traverse), and input sources (e.g., the WEMCO executive vice-president said we have to minimize cost).

(4) Relations among Goals, Components, and Inputs. The rationale must specify the relations among its elements. These might be informal relations (e.g., might depend on, might impact on). Alternatively, they might explicate the logic of the rationale (e.g., is necessary for, is sufficient for, is entailed by).

In essence, the rationale is an argument or "proof" that the plan does what it is supposed to do. It explains what goals the organization intends to achieve, how it will approach those goals, and why it believes its approach will work. Conversely, the rationale also explains what goals and approaches the organization has considered and foregone and why it has done so.

Figure 2 shows a graphic representation of the rationale underlying the updated Topanga-Ventura plan. It includes assertions representing the goals, plan components, and assumptions underlying the plan, along

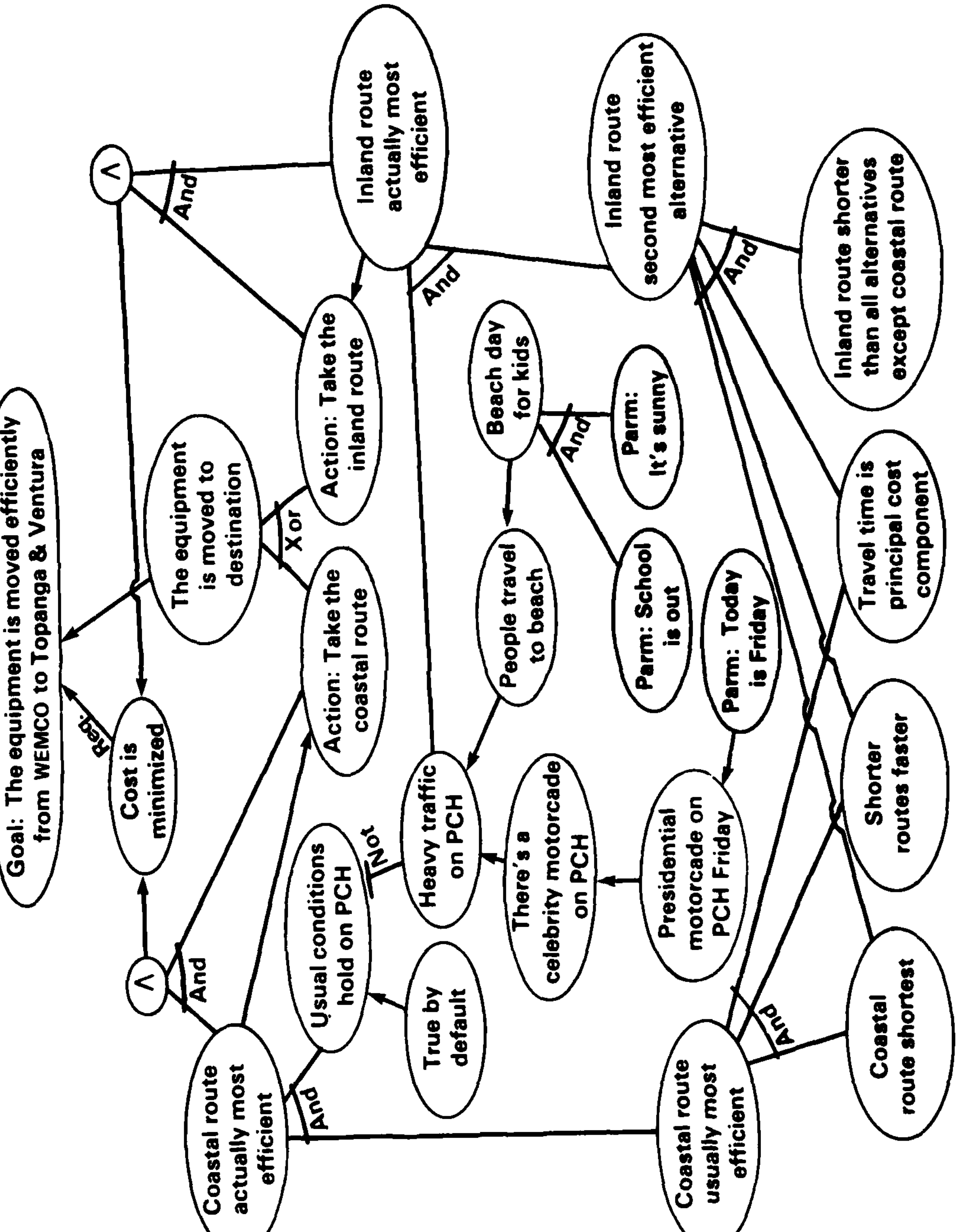

Fig. 2--Plan rationale for the Topanga-Ventura plan.

with relations connecting these assertions in a logical argument. The rationale indicates that the goal is to move the equipment from WEMCO to the intersection of Topanga Canyon Road and Ventura Boulevard, under the constraint that cost is minimized. It argues that the coastal route is usually the most efficient way to achieve this goal because it is the shortest route, shorter routes are faster, and travel time is the principal cost component. However, the rationale also acknowledges that, when there are unusual traffic conditions on the Pacific Coast Highway, the coastal route is not the most efficient way to achieve the goal. Such conditions include people traveling to the beach on sunny days when school is out and Friday morning Presidential motorcades, both of which produce heavy traffic on the Coast Highway. The plan rationale provides an alternative route for these conditions, the inland route. It argues that the inland route should be the second choice because it is the second most efficient route, again based on considerations of route length, travel time, and cost.

The representation used in Figure 2 is one of several alternative representations we are studying and provides the basis for one of the experimental systems we have implemented, WAND. In the next part of this section, we will illustrate how WAND uses this representation to provide valuable re-planning facilities. We will also show how another experimental system, DEMO, uses a simpler representation to provide other facilities.

RE-PLANNING FACILITIES

We have identified four general classes of facilities for inclusion in the PLANNERS' WORKBENCH: record, comprehend, validate, and analyze. We discuss specific facilities in each class below and present examples of several of them, as implemented in WAND and DEMO. To facilitate this discussion, we illustrate each facility with the Topanga-Ventura plan introduced above.

Record

The first task of the PLANNERS' WORKBENCH is to record plan rationales. We have developed the following two prototypical recording schemes.

Figure 2 above shows a graphic representation of WAND's record of the rationale underlying the Topanga-Ventura plan. The following examples illustrate the actual input to WAND for parts of this rationale:

```
[rule 1] Go mutually-exclude <"Action: Take the inland route",
                              "Action: Take the coastal route">
             in "The equipment is moved to destination".

[rule 2] Go conjoin <"Coastal route shortest",
                     "Shorter routes faster",
                     "Travel time is principal cost component">
             in "Coastal route usually most efficient".
```

Rule 1 records the planners' assertion that either of two routes, the coastal route or the inland route, will achieve the goal of moving the equipment to the destination. Rule 2 records their reasoning that the coastal route is usually the most efficient route, based on their assumptions that the coastal route is shortest, shorter routes are faster, and time is the principal cost component. The other information in Figure 1 is encoded in similar English language-like instructions. (For a more detailed description of WAND's representation and implementation, see Hayes-Roth, 1981).

DEMO produces a much simpler version of the Topanga-Ventura plan rationale. Its graphic representation would look similar to the one in Figure 2, except that none of the logical relations would be marked or distinguished. An arrow would signify only that one assertion "depends on" another, or conversely, that one assertion affects another. Inputs to DEMO are also simpler, as illustrated in the following examples, corresponding to rules 1 and 2 above:

1 The equipment is moved to destination depends on Take the inland route
2 The equipment is moved to destination depends on Take the coastal route
3 Coastal route usually most efficient depends on Coastal route shortest
4 Coastal route usually most efficient depends on Shorter routes faster
5 Coastal route usually most efficient depends on Travel time is principal cost component

Dependencies 1 and 2 indicate that moving the equipment to the destination depends on taking the inland route and/or taking the coastal route. Dependencies 3, 4, and 5 indicate that the coastal route's usually being the most efficient depends on one or more of the three assumptions. There is no explicit or implicit interaction between the "premises" on which a particular sentence depends. The premises are simply points made in arriving at the assertions that depend on them. The entire rationale shown in Figure 2 would be expressed as a series of such pairwise dependencies.

Comprehend

An immediate advantage of recording plan rationales is that they provide a basis for comprehending a plan and its genesis. This permits planners to refresh their memories for plans they generated previously or to familiarize themselves with plans generated by other individuals in the organization. It also permits planners to inspect a plan for potential weaknesses. We are developing three types of comprehension facilities: review, brief, and interrogate.

Review permits a planner to work through a plan systematically, reconsidering all of its propositions and the relationships among them. For example, WAND reponds to the command, "go review every sentence," with sentence descriptions like the following one:

```
Coastal route usually most efficient
  This sentence is now UNSPECIFIED
This sentence is a conjunction of
        Travel time is principal cost component
      & Shorter routes faster
      & Coastal route shortest
This sentence is a conjunct included in
        Coastal route actually most efficient
```

This description describes the relationship between the sentence under consideration and its immediate subordinates and superordinate. It also specifies a truth value (discussed below).

Brief permits a planner to convey selected aspects of a plan and its rationale to audiences with special interests. We are developing simple heuristics, such as:

To brief the boss, describe planned actions and their consequences.

This heuristic would select five sentences from the rationale in Figure 2: the two action sentences, their two immediate superordinates, and the top-level goal. It would produce the following brief:

> Take either the Coastal route or the Inland route to move the equipment from WEMCO to its destination at the intersection of Topanga and Ventura. Use whichever route is most efficient in order to minimize cost.

Interrogate permits a planner to examine specific aspects of the plan rationale. For example, suppose the planner wondered what factors might influence the efficiency of the inland route. DEMO responds to questions such as "what immediately affects 'Inland route actually most efficient'?" by reporting the originally recorded dependencies:

Heavy traffic on PCH

Inland route second most efficient

If the dispatcher wished to know the extended set of factors influencing the efficiency of the inland route, the question "what affects 'Inland route actually most efficient'?" would elicit the chain of sentences implicit in those originally recorded, on which the designated sentence depends:

Heavy traffic on PCH
Inland route second most efficient
People travel to beach
Beach day for kids
School is out
It's sunny
Inland route second most efficient alternative
Coastal route is shortest
Shorter routes faster
Travel time is principal cost component
Inland route shorter than all alternatives except coastal route

Other DEMO commands permit the dispatcher to ask the converse of these questions (e.g., "what depends on 'inland route actually most efficient'?") or to explore the relationship between two particular sentences (e.g., "what is the relationship between 'The equipment is moved to the destination' and 'School is out'?").

Validate

Planners and re-planners must validate the plans for which they are responsible, insuring that the plans do what they are supposed to do. We are developing two kinds of evaluation facilities, verify and justify.

Verify permits the planner to re-confirm the assumptions underlying a plan. For example, WAND responds to the command "display every *assumption*":

Coastal route shortest
Shorter routes faster
Travel time is principal cost component
Inland route shorter than all alternatives except coastal route

The planner can then verify each of these assumptions independently.

Justify permits the planner to re-confirm the argument relating particular assumptions and parameter values to planned actions. WAND supports this function by simulating alternative truth values for particular assumptions and parameters in the rationale and working through their ramifications. For example, WAND explicates the argument underlying the default plan in response to the command, "go posit every assumption":

Now supposing Coastal route shortest to be TRUE
Now supposing shorter routes faster to be TRUE
Now supposing Travel time is principal cost component to be TRUE
A ramification: Coastal route usually most efficient is now true
Now supposing Inland route shorter than all alternatives except coastal route to be TRUE
A ramification: Inland route second most efficient alternative is now TRUE
A ramification: Usual conditions hold on PCH is now TRUE
A ramification: (Action: Take the coastal route & Coastal route actually most efficient) is now TRUE
A ramification: The equipment is moved to destination is now TRUE
A ramification: Action: Take the inland route & inland route most efficient) is now FALSE
A ramification: Cost is minimized is now TRUE
A ramification: Goal: Equipment moved efficiently from WEMCO to Topanga & Ventura is now TRUE

Similarly, WAND would work through the arguments in favor of the alternative plan in response to the command, "go posit every parameter":

Now supposing Its sunny to be TRUE
Now supposing School is out to be TRUE
A ramification: Beach day for kids is now TRUE
A ramification: People travel to beach is now TRUE
A ramification: Heavy traffic on PCH is now TRUE
A ramification: Usual conditions hold on PCH is now FALSE
A ramification: Inland route actually most efficient is now TRUE
A ramification: Coastal route actually most efficient is now FALSE
()
A ramification: (Action: Take the inland route & inland route actually most efficient) is now TRUE
A ramification: Action: Take the coastal route is now FALSE
A ramification: Cost is minimized is now TRUE
A ramification: Goal: Equipment moved efficiently from WEMCO to Topanga & Ventura is now TRUE

Analyze

As discussed in the Introduction to this paper, re-planning is a recurring, critical process in most organizations. Plan rationales provide a strong basis for analyzing the strengths and weaknesses of current plans and for designing appropriate modifications. We are developing three kinds of analysis facilities: detect, assess, and update.

Detect helps the planner to notice data that bear directly on a plans efficacy. Vast quantities of information pass through most organizations on a daily basis. Because it is impractical to evaluate the effects of all new data on all aspects of existing plans, the planner must restrict attention to those data that bear on key rationale components. Both DEMO and WAND provide operational heuristics for identifying key components.

DEMO can identify key assumptions or concepts in terms of the number of other sentences that depend upon them. In response to the command "what depends on <designator>?" DEMO produces all sentences in a rationale that depend on any sentence containing the designator. The planner can then identify key assumptions or concepts as those that have at least some criterial number of dependents. Under this heuristic, Coastal route shortest, Shorter routes faster, and Travel time is principal cost component, with nine dependents each, are key assumptions in the Topanga-Ventura rationale. Today is Friday, School is out, and Its sunny, with eleven dependents each, are key parameters. It is easy to see in this simple example, that the identified key assumptions are the underpinnings for most of the logic in the rationale. Similarly, the key parameters determine which of the two planned actions will be taken.

WAND can use similar heuristics to identify key components. However, it can also consider the logical relationships among components. For example, other things being equal WAND can attribute more importance to a sentence that is an independent subordinate of many dependents than to one that has a conjunct. Under this heuristic, Today is Friday is more important than School is out. This makes good sense. If Today is Friday is true, the planned action changes from the default coastal route to the alternative inland route. However, if School is out is true, the planned action does not change unless Its sunny is also true.

Assess permits the planner to judge the impact of new data, changed assumptions, or new parameter values on the plan rationale. Suppose the planner learned that a major landslide had temporarily closed the Pacific Coast Highway and wanted to know how that might impact on the Topanga-Ventura plan. The DEMO command "print PCH" identifies all recorded sentences containing the designator "PCH":

```
Presidential motorcade on PCH Friday
Theres a celebrity motorcade on PCH
Heavy traffic on PCH
Usual conditions hold on PCH
```

The appearance of several sentences concerning PCH and the fourth sentence in particular informs the planner that conditions on the Coast Highway impact on this rationale. To further explore this matter, the planner might wish to know what role "usual conditions" play in the rationale. The DEMO command "what depends on 'Usual conditions hold on PCH'?" identifies:

```
Coastal route actually most efficient
Action: Take the coastal route.
Cost is minimized
Goal: The equipment is moved efficiently from WEMCO to Topanga
        & Ventura
```

Each of these sentences depends on and, as a consequence, might be affected by changes in conditions on PCH. The planner can conclude that the occurrence of unusual conditions on the Coast Highway, such as a landslide, might interfere with the actual efficiency of the planned route and, as a consequence, with cost minimization and achievement of the goal.

A comparable sequence using WAND commands has a slightly different focus. The command "go explain PCH" reports all recorded assertions containing the designator PCH. Each description includes the truth values of the target sentences and their logical relationships to near neighbors. For example,

```
Usual conditions hold on PCH
  This sentence is now TRUE
This sentence is a conjunct included in Coastal route actually
        most efficient
This sentence is enabled by DEFAULT
This sentence is inhibited by Heavy traffic on PCH
```

Now consider a change in assumptions. Suppose that, several years after the development of the Topanga-Ventura plan, fuel prices soared. The organization might decide that fuel, rather than travel time, had become the principal cost component. In order to assess the impact of the new assumption on achievement of the goal, the planner might review the relationship of the original assumption to the goal with the DEMO command "What is the relationship between 'Travel time the principal cost component' and 'Goal: The equipment is moved efficiently from WEMCO to Topanga & Ventura'?." That command would produce <u>all</u> dependency chains linking the designated sentences. One such chain follows:

```
Coastal route usually most efficient depends on Travel time is
        principal cost component
Coastal route actually most efficient depends on Coastal route
        usually most efficient
Cost is minimized depends on Coastal route actually most efficient
Goal: The equipment is moved efficiently from WEMCO to Topanga &
        Ventura depends on Cost is minimized
```

By inspecting these dependency chains, the planner can judge whether changing the designated assumption would interfere with the validity of the rationale.

WAND can test the criticality of an assumption directly with the commands "go doubt (or refute) <sentence designator>." These commands set the truth value of the designated sentence to UNSPECIFIED (or FALSE) and work through the ramifications. For example, in response to the command "go refute Travel time is principal cost component" WAND would respond:

```
Now supposing Travel time is principal cost component to be FALSE
A ramification: Coastal route usually most efficient is now FALSE
A ramification: Coastal route actually most efficient is now FALSE
A ramification: (Action: Take the coastal route) is now UNSPECIFIED
A ramification: Inland route second most efficient alternative is
                    now FALSE
A ramification: Inland route actually most efficient is now FALSE
A ramification: (Action: Take the inland route) is now INLAND
A ramification: The equipment is moved to destination is now
                    UNSPECIFIED
A ramification: Cost is minimized is now UNSPECIFIED
A ramification: Goal: The equipment is moved efficiently from WEMCO
                        to Topanga & Ventura is now UNSPECIFIED
```

If travel time is not the principal cost component, neither the coastal route nor the inland route is demonstrably efficient and therefore, neither is recommended under the rationale. Since there are no alternatives routes, the equipment cannot be moved to its destination, cost cannot be minimized, and the goal cannot be achieved. As this example illustrates, changing key assumptions dramatically changes the implications of a rationale and the plans it justifies.

Update permits the planner to modify a plan rationale and the plans it supports. The main issue here is substitution. What alternative plan components (e.g., actions, resources, parameters, goals) can replace rejected components? Conversely, how does a newly identified option fit into the plan?

A well-documented plan rationale can be a valuable source of information for addressing both of these questions. First, it should record rejected alternatives and the arguments both for and against them. Perhaps a plan component that did not suit the original conditions works well under current conditions. As discussed above, the DEMO command "print <sentence designator>" will print all recorded sentences containing the designator. In a more extensive rationale for the Topanga-Ventura plan, the command "print Action" would identify rejected routes in addition to the planned coastal and inland routes. Using the other DEMO commands described above, the planner could then explore the assumptions underlying the consideration and rejection of these routes and reconsider them in light of the new conditions (e.g., increase in the price of fuel).

The rationale also explicates the desired features of the rejected component and those for which it was rejected. These provide criteria for screening new alternatives. For example, using the DEMO command "affects Action: Take the coastal route," the planner could determine that taking the coastal route depends on:

Coastal route actually most efficient
Usual conditions hold on PCH
Coastal route usually most efficient
Coastal route shortest
Shorter routes faster
Travel time is principal cost component

From this the planner can conclude that, while travel time is no longer a valid efficiency metric, efficiency is the main criterion for screening alternatives.

Finally, the planner can exploit DEMO commands like "<print sentence designator>" and WAND commands like "go review <sentence designator>" to explore potential roles in the rationale for new options. For example, suppose the planner learns of a new route from WEMCO to the intersection of Topanga Canyon Road and Ventura Boulevard: East on I 10, North on Sepulveda Boulevard, and West on Ventura Boulevard to the intersection. The planner observes that this "surface route" is basically an inland route and investigates rationale components related to inland routes with the DEMO command "print 'inland route'":

Action: Take the inland route
Inland route actually most efficient
Inland route second most efficient alternative
Inland route shorter than all alternatives except coastal route

These sentences suggest to the planner that the surface route may be as efficient or nearly as efficient as the inland route, in which case it can function as an alternative route in the Topanga-Ventura plan rationale. The planner proceeds to gather the relevant information and modify the rationale as appropriate.

IV. DIRECTIONS FOR FUTURE RESEARCH

We view the PLANNERS WORKBENCH as an opportunity to combine a variety of state-of-the-art AI methods in a valuable planning aid (see Figure 3). However, it also presents several challenging research problems, as outlined below.

Methods for displaying rationales are a major focus of our current research effort. For the examples discussed above, we used verbal descriptions of particular parts of the rationale. While these may be useful in some circumstances, graphical displays will undoubtedly prove more efficient, as well as more comprehensible in many situations. Our current plan is to conceptualize rationales as maps, like the one in Figure 2. We will then attempt to generalize previously developed interactive map technology for scanning, selecting information, and focusing at different levels of abstraction (Anderson & Shapiro, 1979).

We are also examining the utilities of different ramification calculi. WAND and DEMO use two very different calculi. Our ability to automate specific re-planning facilities depends on the generality of inter-sentence dependency relations and the calculi needed to manipulate such relationships. The choice of inter-sentence dependency relations also constrains the types of briefing heuristics we can develop. We assume that particular ramification calculi and briefing heuristics will be more or less appropriate for different users in different planning domains. This suggests that we may need to develop tailored systems for use in particular organizational environments. In fact, we see the PLANNERS' WORKBENCH evolving as a family of related systems adapted to

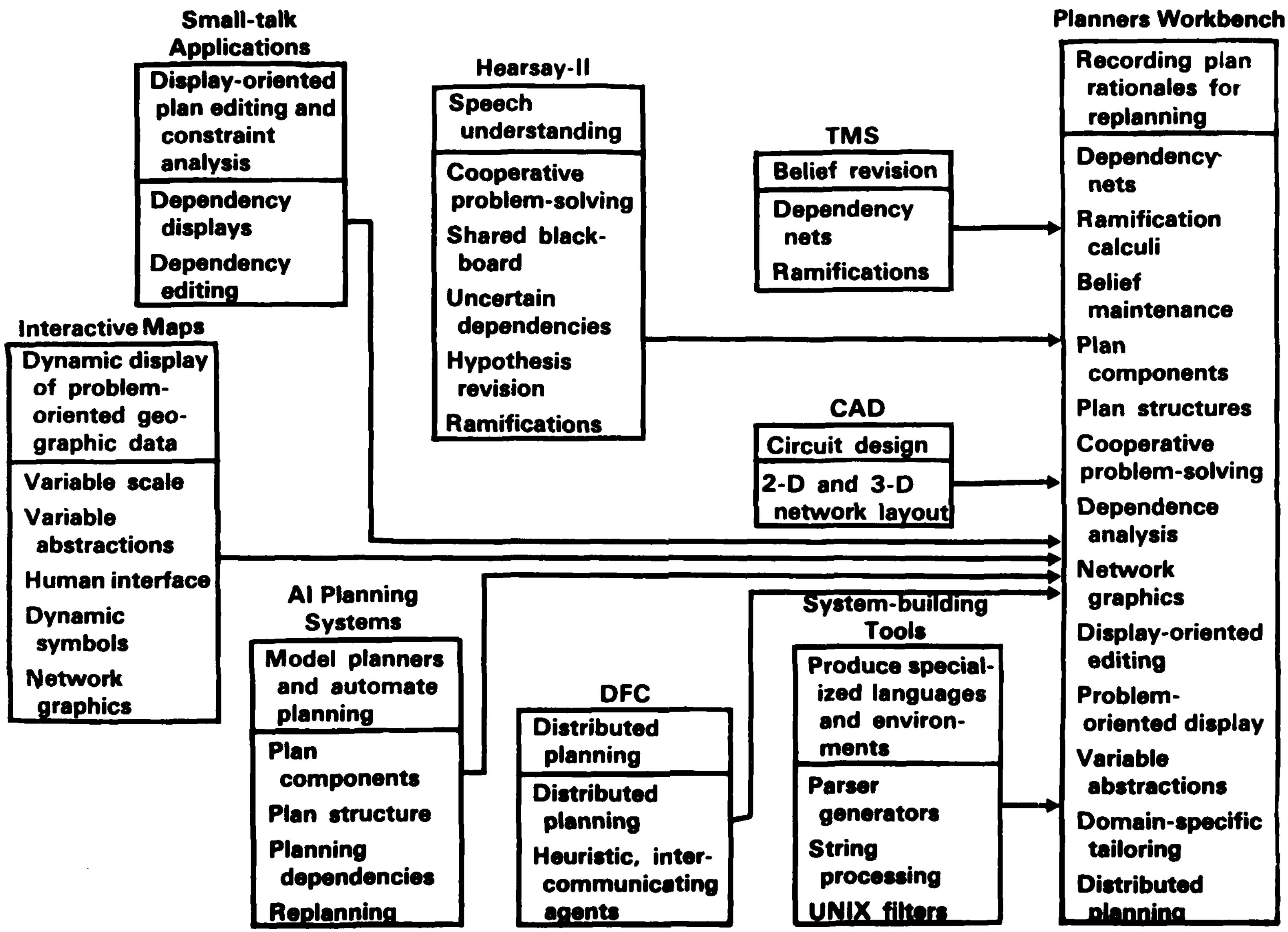

Fig. 3--Impact of previous AI technologies on the PLANNERS' WORKBENCH.

different planning applications.

Finally, while these research issues pose interesting questions in the context of demonstration problems such as the Topanga-Ventura plan, the real challenge lies in transferring the proposed system to large-scale planning environments in which many individuals, using diverse sources of information, cooperate in the development of complex and extensive plans.

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