INTEGRATED PLANNING INFORMATION SYSTEMS: CONTEXT, DESIGN REQUIREMENTS, AND PROSPECTS

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ABSTRACT. This research contributes to the theoretical basis for appropriate design of computer-based, integrated planning information systems. The research provides a framework for integrating relevant knowledge, theory, methods, and technology. Criteria for appropriate system design are clarified. The requirements for a conceptual system design are developed based on "diffusion of innovation" theory, lessons learned in the adoption and use of existing planning information systems, current information-processing technology (including expert system technology), and methodology for evaluation of mitigation strategies for disaster events. Research findings focus on the assessment of new information systems technology. Chief among these findings is the utility of case-based reasoning for discovering and formalizing the meta rules needed by expert systems, the role of the "diffusion of innovation" theory in establishing design criteria, and the definition of client interests served by integrated planning information systems. The work concludes with the selection of a prototyping exercise. The prototype is developed in a forthcoming technical paper (Masri & Moore, 1994).

INTRODUCTION

One can say that the methodological promise of the second half of the twentieth century is the management of organized complexity (the complexity of large organizations and systems, the complexity of theory with a large number of variables), the identification and implementation of strategies for rational choice in games against nature and games between persons. (Bell, 1973, p. 28)

Planning, at times, seems to face a greater challenge than the one proposed by Bell. The urban environment—nature and persons—often exhibit signs of disorganized complexity. A common planning task is to attempt to translate seemingly disjointed data and observations about persons and nature into organized models of the urban environment. Planners do this in the belief such models and explanatory frameworks can help them identify and compare appropriate intervention strategies. They attempt to adopt and use information-processing technology to this end.

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The purpose of this research is to integrate knowledge, theory, methods, and technology relevant to development of an integrated planning information system for disaster-policy analysis. This planning information system is designed to evaluate policies intended to mitigate the effects of earthquakes threatening the Los Angeles area. We have four related objectives. We want to:

1. define a theoretical basis for appropriate design of computer-aided planning information systems,
2. identify design elements determining the adoption and use of planning information systems,
3. encourage continuing assessment of new technologies for planning information systems, and
4. advance toward the next generation of disaster-mitigation policy analysis systems.

This a paper addresses the first three objectives. The fourth is addressed in a forthcoming technical paper (Masri & Moore, 1993).

The appropriate planning role for computer-aided information systems is a topic that appears with increasing regularity in the planning literature (Han & Kim, 1989; Heikkila, Moore, & Kim, 1990; Kim, Wiggins, & Wright, 1990; Langendorf, 1985; Leary, 1988; Robinson, Frank, & Blazé, 1986; Rouhani & Kangari, 1990; Southworth, Chin, & Cheng, 1990; Wright, 1990). However, planners' past attempts to adopt innovative systems have met with only limited success. Traditional decision-support systems are unable to combine validated empirical and judgmental analysis to address unstructured or semistructured problems. These are precisely the types of problems common in planning and policy analysis (Langendorf, 1985). These limitations arise from a number of sources. Traditional decision-support systems are designed to manipulate numbers only, and to seek optimal answers. This requires the quantification of all key variables and agreed-upon decision criteria. Obviously, these conditions are rare.

Expert systems comprise a software technology that can replicate certain aspects of expertise, and can manipulate both qualitative and quantitative knowledge. This technology offers planners new ways of organizing, formalizing, and disseminating context-specific knowledge and problem-solving techniques. Such systems are (somewhat hopefully) viewed as means of "overcoming the current limitations found in current computer-based approaches to problem solving" (Han & Kim 1989, p. 296). Expert systems use the speed and storage capacity of computers to address the qualitative problems planners face in addition to the mechanical, quantitative problems normally associated with computer applications (Leary 1988).

The desirability of integrated systems, that is, of coupling expert systems with existing planning information systems, receives wide acceptance in the field. Opportunities for integration include existing Data Base Management Systems (DBMS), Geographic Information Systems (GIS), and Planning Decision Support Systems (PDSS). Our research is motivated by the growing adoption and use of these systems (Cullen, 1986; Gomi, 1987; Leary, 1988; Ortolano & Perman, 1987; Shangraw, 1987; Wiggins, 1990), by the history of failure visited on previous innovations in public information systems (Hemmens, 1968; Langendorf, 1985; Lee, 1973; Pack & Pack, 1977), by the absence of guiding theory concerning system design and development (Bozeman & Bretschneider, 1986), and the many unresolved questions concerning the successful application of artificial intelligence approaches to planning (Han & Kim, 1990; Langendorf, 1985; Leary, 1988; Ortolano & Perman, 1987).

Two questions must be addressed. First, what is the theoretical basis for the appropriate design, evaluation, and validation of computer-aided planning information systems? And second, how can the importance of integrated planning information systems and artificial intelligence be assessed? Our work to date provides the following propositions, from which our investigation proceeds.
1. The adoption or rejection of planning information systems results from the interaction of planning tasks, intellectual paradigms and knowledge, and information-processing technology in social and technological contexts that change over time.

2. The components of a general computer-aided solution are planning tasks, planning and public-decisions theory, planning methods, knowledge of the general social and technological contexts, knowledge of the specific technical and social context, and the information-processing system.

3. The structural integrity and suitability of the information system is dependent on factors not unlike those that govern the structural integrity and suitability of physical structures. These are system structural attributes, system architecture and design, system materials and components, and the construction methods used to integrate the components and implement the system.

4. Past structural failures in the successful adoption and use of innovative planning information systems are similar to those that govern the adoption and use of other innovations. The theory of “diffusion of innovation” (Rogers, 1983) offers an appropriate explanatory framework.

5. Prescriptions and findings from planners’ experience with computer-aided modelling efforts can offer guidelines for suitable design.

6. The criteria of compatibility is dynamic, and is linked to changes in context, roles, and tasks.

7. Procedural knowledge is not sufficient to undertake complex planning tasks. Substantive knowledge of the problem context is needed to generate solutions.

8. Expert systems may be a suitable component of a planning information system designed for a specific context, because expert systems can provide a means of organizing and disseminating formal and informal elements of substantive knowledge on a contextual specific basis.

9. System verification and evaluation can be undertaken with reference to planning theory and knowledge of a specific problem context. However, external validity requires knowledge of the broader societal and technological context.

10. These contentions can be formalized, and a system consistent with this framework can be constructed and applied to a specific task in a specific setting.

**BACKGROUND AND OVERVIEW**

**Planning and Decision**

Most complex problems require planners to understand a combination of problem dimensions. These include client needs and aspirations, economic aspects, legal and constitutional issues, social demographics, moral guidelines, and technical attributes. The differing aspects of the problem will normally suggest a variety of remedies based on rules of law, rules of science, rules of politics, or moral rules. A key difficulty emerges when rules conflict. A preferential ordering scheme is needed, but is often elusive. The experts on whose opinions planners often rely to help determine the salient technical facts and key variables usually do not provide acceptable means of determining or aggregating social preferences.

Wingo (1987) identifies three decision situations in which planners may be confronted by alternatives requiring preferential ordering. These are simple, compound, and complex decision situations. In simple decisions, a single relevant rule is advanced. The application of the rules to the options is simple and mechanical. Han and Kim (1989) report that most current rule-based information systems in planning use such a rule structure. These systems do not provide a strategy to address conflict among rules. The default strategy is to apply the first rule encountered.
tered. In compound decisions, more than one rule is advanced, but all the rules support the same choice. In many respects, compound decisions are no more difficult than simple decisions.

Complex decisions pose much greater difficulties. In these situations, various rules advocate alternative actions. The most technically efficient alternative may not be the politically acceptable solution. The political solution may also conflict with economic, legal, or moral guidelines. Most major planning problems are complex-decision situations, but there is no agreement on how to quantify the key attributes of a complex-decision situation. The standard approach of traditional planning information systems is to exclude nontechnical variables from the analysis.

This is clearly inadequate. The literature calls for planning analysis that incorporates judgmental data about social and political issues with more traditional modes of technical and economic analysis (Dror, 1971; Saaty & Kearns, 1985). Planning systems designed for complex-decision situations must include the meta rules planners need to help evaluate the political and social attributes of planning problems. These meta rules govern rule choice when rules conflict. Attempts to formalize a process of discovery and validation of such meta rules is a pervasive concern among designers of rule-based systems (Han & Kim, 1989; Waterman, 1986).

Wingo (1987) offers a solution based on a normative planning approach that can discover and formalize meta rules by adopting an analysis of problem archetypes and associated rule structures. Wingo argues that by exploring the structures of decision situations, certain common features emerge. Classifying decision situations by their common attributes makes possible the development of archetypal resolutions, or, in this case, the appropriate meta rules. The contingency approach outlined by Alexander (1984) follows a similar logic.

Such case-based reasoning is a common activity for lawyers and judges. Ashley and Rissland (1988) describe an expert system for modelling legal expertise utilizing the case-based approach. The Ashley and Rissland system helps attorneys analyze and develop their arguments about new cases in terms of the most relevant precedent cases. Their system contains a Case Knowledge Base (CKB) dealing with a specific body of law. The computer program solicits information about the current case from the user, and identifies a neighborhood of cases in the CKB that share important features with the current case. Further changes in the current case descriptions reposition the current case closer to some precedents and further from others.

This approach is promising for several reasons. The method does not seek meta knowledge that is applicable to all contexts, but argues that progress can be made by further study of the link between a context and an appropriate resolution. Secondly, it recognizes that the rules defining physical science are unlikely to be suitable for planning. In a field like planning, where the rules are ill-defined, incomplete, controversial, or inconsistent, simple rules and deductive problem-solving approaches must be supplemented by an analogical, reasoning-based approach that relies on an exploration of precedents.

**Planning and Theory**

Information-system design also depends on relevant planning theories. Theory impacts the way planners frame problems and choose solution methodologies. Theory may also define the required information, and thus, the ultimate design of information-processing tools. Unfortunately, the planning field’s attempts to identify appropriate theories conflict, particularly those efforts that attempt to transcend context. Dyckman (1969, p. 300) observes that theory cannot be independent of its societal context, “The theory of planning must include some theory of the society in which planning is institutionalized.” McGuire (1983) proposes a “contextual” approach to the selection of appropriate theory. He argues that all theory can be viewed as true a priori, but only in limited situations. Lim (1987) argues for a contextual perspective similar
to McGuire's. He contends that an appropriate choice of theory can only be determined in the specific context of the application, calling for a "Swiss knife" approach to planning theory.

We adopt this theoretical plurality as a standard against which to measure the appropriateness of planning information systems. This criterion implies a flexible design standard that allows data and system structure to adapt to the information requirements imposed by various theories and approaches. A suitable system design should provide planners with a tool kit of theory, designed to help them understand, evaluate and validate, inform, communicate, and persuade.

Planning and Information Processing

Planners' involvement with computers dates to the early 1960s. Planners' initial access to (mainframe) computing technology was indirect. Specialized departments made up of computer specialists served as intermediaries. Computer specialists developed planning applications for planners, taking responsibility for exercising and maintaining these systems. This tended to be very expensive. Not surprisingly, diffusion of these applications among planning departments was limited.

By the early 1980s, the widespread diffusion of inexpensive personal computers, and the introduction of easy-to-use, off-the-shelf software provided planners with direct access to computers (Whited, 1982). Harris (1989) identifies three different types of planning tasks that involve the use of computer technology. The first type of task involves planning rules. Planners negotiate, bargain, explain, and argue about planning rules. Simple information systems are usually sufficient to support these tasks. Such systems can help planners prepare their positions or present supporting facts.

The second type of planning task Harris (1989) identifies is more complex. These tasks involve the administration and evaluation of rules and regulations to facilitate either private-market solutions or appropriate public intervention.

Third, planners make plans. These may take the form of generalized guidelines, or may be expressed in clearly detailed instruments such as a zoning ordinance. Plans usually require the integration of information about the problem context as to persons, nature, and appropriate means and ends. Some of the required information for making plans is formal, such as legal requirements or scientific attributes. Some of this information is informal, such as personal judgments, experience, and intuition. Experts often rely on informal information when making decisions about which formal information is incomplete, or difficult to obtain.

Planners use and help shape information-processing technology appropriate to their tasks. The tools produced by and for the process are planning information systems. Han and Kim (1989) classified the information systems used by planners into Database Management Systems (DBMS), Decision Support Systems (DSS), Geographic Information Systems (GIS), and Expert Systems (ES). In light of Harris' analysis, we add three more categories. These are "simple systems," Planning and Control Systems (PCS), and Integrated Planning Systems (IPS).

Simple Systems

Simple systems are the most widely used in planning practice. Off-the-shelf software is used in incremental, often unrelated steps to perform various calculations and small information-processing tasks. Word-processing programs and menu-driven spreadsheets are examples.

Database Management Systems

Database Management Systems (DBMS) are used for data storage, processing, and retrieval. Their dominant use in planning is to organize information about citizens, the urban environment, land-use, and physical stocks. The City of Los Angeles Land Use and Planning Analysis
and Management System (LUPAMS) is an example. The database contains information about the various characteristics of the city housing stock. The incorporation of Fourth Generation Languages (4GL) with syntax similar to the English language into DBMS has greatly enhanced these systems' ease of use.

**Decision Support Systems**

DSS contrast with DBMS in that DSS support specific types of decisions. DSS are usually algorithmic in nature. Mathematical models are a common example of DSS for planning. Applications include economic analysis, land-use planning, transportation-systems design, and policy evaluation. These models are usually closely linked to a particular planning theory and methodology.

**Planning and Control Systems**

PCS are designed to aid planning and control activities at two levels: large-scale planning and project planning. Examples of large-scale applications include the programs used by government to translate policy objectives and general allocations into specific plans, programs, and budgets. These Planning, Programming, and Budgeting Systems (PPBS) are strongly procedural in their approach to planning. The analysis requirements inherent in PPBS is probably the method's principal contribution (Cleland & King, 1968). The other class of PCS addresses a more "micro" level of planning. Project Planning and Control Systems (PPCS) often incorporate network analysis methods such as the Critical Path Method (CPM) or the Program Evaluation and Review Technique (PERT). Network plans represent projects in terms of relationships among the critical project elements. These elements are assigned resources (manpower, equipment, materials, dollars). PPCS approaches make it possible to construct schedules and forecasts, and to monitor deviations between plans and actual performance.

**Geographic Information Systems**

Harris (1989) notes that planners are "visually oriented," and that planning tasks often require spatial analysis. GIS are very appropriate tools for these activities. These systems integrate a database of information about urban form with graphic representations of the locations of these characteristics. This information is displayed on linked, coded maps. Some GIS are capable of creating sophisticated multilayered maps, including 3D maps. Planners at the city of Los Angeles are in the process of using such a system to process and spatially locate and display seismically unsafe structures. By overlaying unsafe structure maps with maps showing high risk geologies, planners can locate areas at greatest risk, and overlay this information on maps showing the socioeconomic-economic attributes of area residents.

**Expert Systems**

An ES is a computer program that uses a model of human reasoning to replicate expert approaches to problem solving. Ideally, the program would reach the same conclusions a human expert would reach if addressing the same problem. ESs have their roots in Artificial Intelligence (AI) research. The "AI" label was invented by John McCarthy in 1956. The term includes a range of research disciplines, including artificial neural networks, natural language processing, robotics, computer vision, machine learning, and knowledge-based (or expert) systems. ESs have become operational outside AI research laboratories only during the last decade.

Developments in the field of expert systems parallel some of developments in planning theory. Both areas of inquiry have moved away from a preoccupation with general problem solving, toward less ambitious attempts to solve problems in narrower contexts. Early AI research focused

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on the creation of computer programs for solving any type of problem. These efforts met with failure. Newell and Simon's (1963) General Problem Solver (GPS) is the classic example. While some advances were made, such as the development of strategies for reducing solution spaces, the GPS was primarily confined to limited applications such as theorem-proving (Leary, 1988).

By the late 1970s, AI scientists recognized that the problem-solving capacity of a computer program depends on the knowledge it encodes in addition to the representation and inference techniques it applies. This paradigm shift led to the development of special-purpose programs, and systems that were expert in some narrow problem area. Early examples of these ESs include MYCIN, PROSPECTOR, and XCON (Waterman, 1986). These contextual systems are also referred to as knowledge-based systems.

ESs are further distinguished from conventional computer programs in several important respects:

1. The knowledge base (facts and rules) is separate from the inference engine (the reasoning mechanism).
2. ESs reason with domain-specific knowledge that is symbolic as well as mathematical.
3. These systems are knowledge-intensive.
4. ESs use domain specific heuristics, focusing on solutions that are feasible rather than optimal.
5. Some of these systems are able to perform as well as specialists in certain problem areas.
6. These systems are able to clarify what they know, and the reasoning behind their answers.
7. And, ESs can learn and remain flexible (Buchanan & Shortliffe, 1984; Han & Kim, 1990; Waterman, 1986).

ESs are easier to understand, build, and change than conventional programming approaches, since their design requires a nonprocedural if-then structure, and they are built by using high-level languages with syntax similar to English, or by using menu-driven development shells. However, they are less modular, harder to control, and slower than procedural systems. Consequently, planners integrating ESs into their applications should assign to the ES component only those tasks that would be less efficient if assigned to conventional programs.

**Integrated Planning Systems**

No complete definition of an IPS exists. The common use of the term connotes the combining of different classes of software in a single application. Urban-planning applications of integrated systems are in the early stages of development, and most of the literature is of a theoretical nature. Experience is limited, and appropriate design guidelines remain unclear. However, certain contextual elements are understood. The planning problems IPSs address are complex, and involve varied tasks. Their solution requires the integration of knowledge, data structures, and information-processing tools.

Policy-making is a form of plan-making that embodies the characteristics of a complex-decision situation, where the facts and rules are ill-defined or incomplete. This requires reliance on expertise, and systems that process both traditional and judgmental data. This type of problem is most appropriately addressed by IPSs that include an ES component. Success depends on knowledge of the problem; of valid ends and means; and of planning paradigms, planning methods, and the nature and rules of the setting in which the activity takes place.

**DESIGN OF PLANNING INFORMATION SYSTEMS**

**Verification, Evaluation, and Validation of Planning Information Systems**

Verification is a measure of system responsiveness to the characteristics of the innovation. Relevant rules and tests determine if the tool is sound. Does it conform to key structural rules?
Is its design compatible with the empirical requirements of the problem context? Does it employ suitable material, components, and construction methods? Questions of internal consistency are addressed at this level.

Evaluation measures the tool with respect to the perceived characteristics of the primary adopters: in this case, planners and public officials. Is the tool compatible with needs of planners and policy-makers? A tool may be analytically sound, and technically superior to its predecessor, but fail the test of compatibility with the technological skills of target adopters.

Validation is the more difficult, and the most important of the three measures. The objective here is to answer questions that transcend matters of internal consistency, or the planner’s individual and organizational needs. For the design of suitable planning information systems to be valid, the systems must account for factors beyond the characteristics of the innovation itself. While system evaluation can be undertaken with reference to internal consistency and numerical accuracy, validation comes from system appropriateness relative to the values of the larger social and technological context. We are less interested in the question of whether the system solves the problem correctly. Rather, we are interested in whether it solves the right problem.

Planners are appointed to facilitate societal purposes. These societal purposes and values are the appropriate references for validation exercises. For example, a system may pass tests of internal consistency, and compatibility with bureaucratic adopters’ needs, as outlined by Downs (1967) or Allison (1971), and yet be invalid if it inhibits such social values as openness and democratic participation. Fischer (1980) and Wingo (1987) offer validation schemes that account for the values of the broader setting of the policy-making process.

The absence of clear evaluation and validation approaches has not dampened the enthusiasm of information-system developers with respect to the suitability of their systems for planning. These advocates usually avoid issues of system validation, and focus attention on the technical merits of the solution in terms of its technological efficiency and, to a lesser extent, in terms of its internal consistency. The literature describes what can be done, but is unclear on the question of whether what is being done is being done correctly, or if the right problems are being solved. Some aspects of system accuracy can be measured as a function of the system’s internal consistency with its own theoretical assumptions. But answering questions pertaining to external validation requires clearer notions of what constitutes suitable, valid, planning systems.

Though formal theory to guide the development of appropriate planning information systems is in short supply, other bodies of problem-relevant literature are available. These literatures addresses four key areas, including:

1. the history of information-processing tools in planning, and the sources of the difficulties encountered in their adoption and use;
2. the changes in the social and technological context of planning created by newer information and communications media, which has impacted the roles of the planner, and the tasks and tools of planning;
3. ES technology and other information-processing advances that are likely to contribute to the construction of integrated planning tools; and
4. planning thought, concerning appropriate problem frames and the discovery of suitable ends and means.

Planners are often expected to design, construct, and evaluate their own tools, including information-processing tools. This requires that the details previously dismissed as outside the concern of planners be incorporated into discussions of computer-aided planning tools. We argue that it is in the missed details associated with these efforts that planners encounter problems in the successful adoption and use of innovative technologies. We classify these details, or system characteristics, into four sets of design elements. These are:
1. system structural attributes,
2. system architecture,
3. system materials and components, and
4. system construction methods.

Failure of structural attributes will ultimately lead to rejection and abandonment of the system. The influence of this class of attributes extends beyond planning information systems, governing the diffusion and adoption of innovations. The theory of “diffusion of innovation” (Rogers, 1983) defines structural attributes in terms of:

1. relative advantage, or the perceived superiority of an innovation over its predecessor;
2. compatibility, or the innovation’s consistency with existing values, needs, and past experience;
3. complexity, or the innovation’s difficulty to be understood and used;
4. trialability, or the degree to which an innovation may be experimented with on a limited basis; and
5. observability, or the adoption of an innovation as a function of observed results.

The architectural attributes of the system are related more closely to its intended use. The usefulness of an information system in addressing complex planning problems depends on its representation and inference techniques, and on the system’s knowledge of the specific technical problem and the problem’s social and political setting. The intended tasks and problem contexts determine the sophistication of embedded theory and knowledge. In addition to providing a link between the system and the intended setting, the architecture of a planning information system should permit the system to be used to address technical and distributional questions, to process conventional and judgmental data, to adapt to multiple theories and methods, and to communicate and persuade.

The system’s materials and components are defined by software and hardware. Sophisticated planning systems can and should be constructed from materials and components that are widely available, well documented, relatively inexpensive, and easy to use. Inappropriate system material and components, such as inaccessible software, can reduce the diffusion, adoption, and usefulness of a good planning methodology.

The system construction methods relate to the successful integration of all the identified knowledge, methods, and technology. Decisions about construction methods can reduce the effort required for system construction and documentation, and impede or enhance the system’s flexibility and adaptation. Writing software in terms of modular building blocks defined by specialized, addressed, microprograms simplifies development and maintenance. Each module’s address identifies the relationship of the software unit to other units in the system. Used in conjunction with a system map, this method reduces traditional documentation requirements, and facilitates future refinement and modification. Programs that rely on difficult-to-follow approaches, or do not provide adequate documentation, can reduce opportunities for refinement by others. This can lead to reduced use, and eventual rejection of the innovation.

**Diffusion of Innovation**

Experience and perception about planning information systems leads to their success through adoption and use, or failure through rejection and eventual abandonment. Feedback from the outcome of previous efforts affects future efforts, knowledge, technology, and the social and technological setting itself. All of these elements are dynamic and may change over time. (See Figure 1.)
Appropriate system design implies design decisions of sufficient quality to insure system adoption and use. Innovations in decision aids for planners have failed before, for a wide range of reasons. The literature offers various alternative explanations. A practical, theoretical view must account for these alternative explanations and multiple levels of influence. The theory of "diffusion of innovation" (Rogers, 1983) provides such a framework. The theory outlines the key elements in the diffusion of an innovation as the innovation itself, and the fact that the innovation is communicated through individual channels over time and among members of a social system. (See Figure 2.) The theory further indicates that the determinants of adoption and use of innovations can be organized into three levels of influence. These are: the characteristics of the innovation, the characteristics of adopters, and the characteristics of the intended setting.

FIGURE 2. Stages in the Diffusion of Innovation Process (Rogers, 1983, Figure 5-1, p. 155; Reprinted with the permission of The Free Press, a division of Macmillan, Inc. from Diffusions of Innovations (3rd ed.) by Everett M. Rogers. Copyright © 1962, 1971, 1983 by The Free Press.)
Characteristics of the Intended Setting

Perhaps the best-known study on the diffusion of innovation in planning is that undertaken by Pack and Pack (1977). The purpose of their study was to identify the determinants of adoption and use of urban land-use models. Pack and Pack found that political interest was involved in the process after adoption, because the models clarified what is to be gained and lost (and by whom). Politics caused models to be discarded.

Other studies of energy use and economic models find that computer-based information systems are used most often to legitimize decisions made on other grounds (Greenberger, 1983; Kraemer et al., 1987). Nevertheless, the process of modelling has a constructive role in facilitating negotiation and bargaining among contestants in local development and land-use decision-making (Dutton & Kraemer, 1985). At the same time, the use of modelling tends to increase the distance between the participants in the decision-making process and members of the lay public, who are left out of the modelling process (Dutton, 1988).

The findings support the arguments made by Downs (1967), who indicates that the future adoption and use of computer-aided systems will depend on the ways in which these systems increase the effectiveness and power positions of the actors involved. Downs (1967, p. 210) argues that “we must shift our attention from the dazzling technical capabilities of computer systems to the ways in which men apply those systems in the real world.” Unfortunately, the current literature on applications of ES to planning remains focused on the “dazzling technical capabilities” of these systems, and mostly ignores the question of how to ensure compatible design with the ways decision-makers actually apply these systems in the real world.

Characteristics of the Adopters

The role of the individuals involved in the adoption and use of the systems is significant. Pack and Pack (1977, p. 90) found that “the most important factor in explaining the decision to develop a land use model is embarrassingly simple if one is interested in complex explanations,” since it appears to be “the presence in an agency of staff members with some responsibility for program development who advocate model adoption.”

Urban-development model failures may be similarly blamed on the individuals involved in development. Problems include inadequate personnel, and poor communication between the computer programmers and decision-makers (Hemmens, 1968). More recently, the American Planning Association (1987) identified the required training of staff members as the leading difficulty associated with computer applications in economic development.

Characteristics of the Innovation

System incompatibility with planning needs is singled out as a leading cause for rejection or abandonment of some land-use models. As Langendorf (1985) points out, computers are most useful as decision aids when applied to well-structured problems. However, many of the problems planners confront may be more accurately classified as semistructured, or even unstructured. Langendorf (1985, p. 422) summarizes the difficulties of the decision-makers attempting to use these models as follows.

1. Decision makers do not understand and trust the models.
2. Decision makers often cannot specify in advance what they want. That is, they require a trial and error sequence that the models typically do not accommodate.
3. Decision requirements change, and the models typically lack the flexibility to respond to changing needs.
4. Decision making often involves judgmental and other soft criteria, multiple criteria or multiple objectives, and individual and group preferences that the formal models typically do not accommodate.
Pack and Pack (1977) also cite the inability to represent variables accounting for planning needs as a source of model failure. Lee (1973) identifies “seven classes of sins” contributing to the failure of early large-scale modelling attempts. These are:

1. excessive comprehensiveness: the models are designed to replicate too complex a system in a single stroke, and expected to serve too many purposes at one time;
2. grossness, or too high a level of data aggregation;
3. data hungri ness: a San Francisco housing model needs 15,000 items of data for a single application;
4. unmet claims, or the differences between the models’ intended behavior and the actual equations or statements that govern output;
5. complicatedness, or the number of variables involved;
6. numerical accuracy: the accuracy of the output was unknown due to numerical rounding errors; and
7. expense.

In the language of “diffusion of innovation” theory, these systems lack compatibility, observability, relative advantage, and are too complex. These characteristics will lead to structural failure in system adoption and use, regardless of the task the system is designed to address.

The characteristics of the social and technological setting of planning continue to change in ways that are difficult to predict, but some relevant trends are clear. These involve the increasing democratization of information, and the expanded role of information and communication technologies in shaping the environment of planning and the choices of planners. These forces also affect the role and means of planning and, we contend, the nature of the planners’ tools.

**PLANNING, INFORMATION TECHNOLOGY, AND SOCIETY**

The U.S. Office of Technology Assessment (1988) reports that the nation’s investment in information technology doubled between 1978 and 1985, accounting for 40% of all new investment in plants and equipment. Rogers (1986, p. 10) defines an information society as “a nation in which a majority of the labor force is composed of information workers, and in which information is the most important element.” The U.S. became an information society somewhere between 1955 (Beniger, 1986) and 1975 (Cleveland, 1985a), depending on how an “information worker” is defined.

A key issue in the study of the social and political impacts of communications technology is the way in which advances in computing and telecommunications affect the power of individuals. The same technologies have been alternatively described as empowering or enslaving, as “technologies of freedom” (Pool, 1983), or as technologies of “control over large groups... by small groups” (McDermott, 1969). Mowshowitz (1977) contends that “computer-based information systems furnish means of centralization of power to an extent which could not have been imagined by absolute rulers of the past.” However, recent reports in the press warn despots to beware of new media that will allow citizens to “challenge their governments” and “rejoice at their new-found freedom and knowledge” (The Economist, 1988). Further review of the literature does not reconcile the contradiction, but does provide important lessons concerning the changes taking place in the environment of planning.

The debate in the literature concerning the role and effect of information and communications technology on the environment of planning defines at least three different schools of thought. We designate these the Democratic View, the Elitist View, and the Status Quo View. We also offer a fourth perspective: the Tribal View.
The Democratic View

The Democratic View holds technological choices to be a function of public preferences. These preferences are expressed via the market place, and democratic institutions. Plural interests are served. The effects are countervailing (Mesthene, 1969). The principal social transformation is a shift toward decentralization (Naisbitt, 1982), ushering in the demise of hierarchy (Cleveland 1985b), and increasing choice and freedom (Pool, 1983). The transformations wrought by information technology are argued to lead to more access, involvement, and participation by individuals, with optimistic implications for questions of equity, fairness, consensus, and cooperation.

The City of Santa Monica in California illustrates how changing technology and social expectations affect the design of planning information systems. Citizens of Santa Monica requested and received access to the city government computer network. Their objective is to be able to read city staff reports sent to the city council (Dutton, 1988). The system is being expanded to provide further public access. Openness and ease of use have emerged as design criteria.

The Elitist View

The complex nature of certain technologies suggests that they will be beyond the understanding of most. This perspective vests control in the hands of an economic or governing elite that employs technical experts to enhance their control. The interests served are those of groups such as the military-industrial complex rather than the public at large. Public preference is controlled by marketing techniques (McDermott, 1969; Mosco, 1982). Under this scenario, the analytical difficulty facing planners, of how to discover and calculate social preferences is a mute issue. Preferences are not discovered. They are shaped.

The logical outcomes provided by this perspective are the opposite of the outcomes associated with the Democratic View. The elitist outcomes include stratification, manipulation, and extreme centralization. “Many will know, yet few will know,” and those few who know will be setting the agenda for the remainder of society (Lowi, 1981).

The Status Quo View

This view discounts the hypothesis that communication and information technologies bias the distribution of power in either democratic or elitist directions. The premise is that these technologies are social constructs, and as such are a malleable political resource that can be used to reinforce the prevailing power structure. It makes no difference whether the prevailing power structure is democratic or elitist (Danziger, Dutton, Kling, & Kraemer, 1982; Dutton, 1988; Kraemer & Dutton, 1979; Laudon, 1974).

The Need for an Alternative View

The most problematic aspect of the three perspectives is their selective attention to certain attributes of the information question while neglecting other equally relevant considerations. The difficulty with the status quo is not the contention that information technologies are malleable. They are. What is unclear is how the prevailing power structure would maintain control to reinforce its position. Many of the technologies are so widely diffused that it would require great expense and manpower to monitor and control even a plurality of users. Controlling satellite transmissions, wireless phones, video cameras, fax and copy machines, and modem-equipped personal computers is no longer feasible, if it ever was. Examples of failed attempts by governments abound.
The Elitist Views are enlightening in that they highlight dependency on expertise, and the relationship between information and power. However, they fail to make the important distinction between the economic elite, the governing elite, and technocratic elites. Assuming that the interests of different elites are congruent is an oversimplification. Such a simplification may obscure power shifts within elite groups favoring increased dependency on technical expertise.

Another weakness of the elitist perspective is the presumption that technology alone is sufficient for control. National scale tests of the hypothesis are rare. However, the Shah's experience in Iran is instructive, because it highlights the limits of technology. In prerevolutionary Iran, big media consisted of government-controlled radio and television, supported by a large intelligence and surveillance service. However, the official media was unable to control socially mobilized individuals with their little media of telephones, copy machines, and tape recorders (Tehranian, 1979).

The key assertion of the Democratic View is that the new media exhibits a structural bias toward empowering individuals and enhancing their freedom. However, the contention ignores the observation that barriers to the wide diffusion and use of these technologies exist. If these barriers are primarily expense and literacy requirements, then income and education will be positively correlated with diffusion and use of innovations. In the case of personal computers, research findings support this hypothesis (Anderson & Harris, 1984; Dutton, Rogers, & Jun, 1987). As the cost of media continues to drop, we can expect income to play a diminishing role; but literacy requirements will continue to be a barrier for a large segment of the population (Dutton, Rogers, & Jun, 1987; Rogers, Daley, & Wu, 1982).

The central question for planners and policy-makers is not whether new technologies empower individuals and increase democratic participation in policy-making. Rather, the question is who will be empowered and whose democratic participation will increase. Planners need to recognize that the constraints that are unevenly distributed, and that the design of their information tools will effect who will be able to participate and who will be excluded. Policy-making for the informed requires adjustments in the role and tools of planning. All three perspectives provide a partial description of the planning's evolving information environment. All three are true in limited contexts. Their common ground defines the Tribal View.

The Tribal View

The Tribal View is that changes in information and communications technology lead to a redistribution of empowerment and constraints, and to different forms of tribal political participation, with increased emphasis on direct action. We define tribes as social clusters of networked individuals (Rogers & Kincaid, 1981), seeking empowerment and protection from the outside world. Information and communications technologies are central to the tribe's cohesion, to its ability to organize and respond to threats (perceived or real), and to its ability to engender public support for its position. The social manifestations implied by the Tribal View can be observed in the neighborhood movements, environmental groups, consumer groups, and direct action (public referenda) groups.

The American political system is not the only place this phenomena can be observed. Lawson and Merkl report, in a study of many countries (West Germany, Sweden, Italy, Switzerland, Britain, France, Denmark, Israel, India, Taiwan, and Ghana), that the formation of single-issue movements is a global event, that special-interest groups are assuming party-like status, and that alternative political organizations are winning “startling overnight victories as hitherto dominant parties lose the confidence of their electorate” (Lawson & Merkl, 1988, p. 3). Very little is known about the mechanisms of these transformations. Explanations are speculative because very little data exists to support or refute the notions implicit in the explanations. However, it is clear that these movements are a transformation of the social and political environments of planning. The transformation may be rapid.
Friedmann (1987), in a recent book on planning in the public domain, summarizes the difficulties planners are facing.

Talk to planners, and nine out of ten will describe their work as a “failure” or of “little use.” They will say, “we no longer know what to do. Our solutions don’t work. The problems are mounting.” If they are right — and who would quarrel with them? — we are forced to conclude that mainstream planning is in crisis. (p. 311)

We offer no opinion on Friedmann’s assertion of crisis, but we suspect that many of the difficulties planners encounter relate to the ambiguities associated with these new tribal clients.

Implications for Planning and the Design of Planning Information Systems

Planners must recognize that, in the current setting of planning, information is the dominant resource, and that an information-rich polity will organize and demand participation in decision-making. Cleveland (1985b) describes the setting as one in which authority is delegated upward. Planning for the informed requires consultation and persuasion if that planning is to produce action. Openness and less secrecy will characterize the planning process, “not necessarily as an ideological preference, but as a technological imperative.” To be valid in this context, the design of planning tools must serve the broader context of the problem. Accurate data processing alone is not sufficient. The design must not inhibit participation and review by this new class of decision-makers.

Forrester’s (1980) application of Habermas’ (1979) “communications theory of society” helps explain how planning can be formalized as attention shaping communicative action. The design of information-processing tools may also work “to thwart or foster a democratic planning process” (Forrester, 1980, p. 275). Forrester’s focus was with the nature of the planning message, and its attributes such as language, timing, and presentation. We add that the medium is no less important.

Planning information systems must go beyond data processing tools. Planning information systems must be tools of participation and persuasion. This criteria calls for the formalization of such design prescriptions as transparency, public access, ease of use, and the systems’ structural attributes. The theory of “diffusion of innovation” (Rogers, 1983) provides a suitable organizing framework. In particular, it is possible to improve verification, evaluation, and validation of prototype systems by interpreting the four sets of design elements in the theoretical context provided by “diffusion of innovation.” A 3 x 4 matrix of questions tests compliance with “diffusion of innovation” rules, and organizes lessons learned from system-development efforts. (See Table 1.) How a particular prescription is to be formalized is determined at the stage of applying the general prescriptions in the intended setting. At this point, general design guidelines can be further clarified in the form of engineering specifications. Relative terms as “adequate disaggregation,” “flexible,” and “easy to use” are given dimension by the specifics of the context in which they are to apply.

RESEARCH AGENDA: PROTOTYPING

Policy analysis is the highest-order planning task that planning information systems are designed to support.

Policy analysis is a form of applied research carried out to acquire a deeper understanding of sociotechnical issues and to bring about better solutions. Attempting to bring modern science and technology to bear on society’s problems, policy analysis searches for feasible courses of action, generating information and marshaling evidence of the benefits and other consequences that would follow their adoption and implementation, in order to help the policy-maker choose the most advantageous action. (Quade, 1982, p. 5)

Quade’s definition is useful as a guiding perspective. However, our definition of “policy-maker” extends beyond traditional use to include concerned citizens and other stakeholders.
## TABLE 1. Improved Planning Information System Verification, Evaluation, and Validation

<table>
<thead>
<tr>
<th>System attribute</th>
<th>Verification System / Planning task</th>
<th>Evaluation System / Planning role</th>
<th>Validation System / Planning setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural attributes</td>
<td>Is it better than what it replaces?</td>
<td>Do decision makers trust it more?</td>
<td>Is it more consistent with stakeholder values?</td>
</tr>
<tr>
<td></td>
<td>Is it complex?</td>
<td>Do decision-makers understand it better?</td>
<td>Is it too complex for stakeholders?</td>
</tr>
<tr>
<td></td>
<td>Is it trialable?</td>
<td>Can decision-makers experiment with it easily?</td>
<td>Can stakeholders try it?</td>
</tr>
<tr>
<td></td>
<td>Is it observable?</td>
<td>Are results represented appropriately?</td>
<td>Can stakeholders see and understand the outputs?</td>
</tr>
<tr>
<td>Architecture</td>
<td>Is it compatible with the task?</td>
<td>Is it compatible with the role?</td>
<td>Does it incorporate values operating in the setting?</td>
</tr>
<tr>
<td></td>
<td>Does it allow for adequate disaggregation of data?</td>
<td>Is it compatible with skills?</td>
<td>Does it support mutual learning?</td>
</tr>
<tr>
<td></td>
<td>Does it allow for unstructured problem solving?</td>
<td>Does it support communication and persuasion?</td>
<td>Does it support democratic action?</td>
</tr>
<tr>
<td>Materials and components</td>
<td>Is the technology accessible in terms of diffusion and cost?</td>
<td>Does it combine theory and formal and informal data?</td>
<td>Do the technologies present educational barriers?</td>
</tr>
<tr>
<td></td>
<td>Is the technology sophisticated in terms of comprehensiveness and integration?</td>
<td>Does it include a tool kit?</td>
<td>Are the methods and language coherent to stakeholders?</td>
</tr>
<tr>
<td></td>
<td>Can the quality of data be identified?</td>
<td>Can irrelevant data be filtered out?</td>
<td>Is meta knowledge consistent with values operating in the setting?</td>
</tr>
<tr>
<td></td>
<td>Can uncertainty be treated?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction methods</td>
<td>Is the documentation adequate?</td>
<td>Can modifications be made?</td>
<td>Is it adaptable to changing needs?</td>
</tr>
<tr>
<td></td>
<td>Is the logic transparent?</td>
<td>Does it support data gateways?</td>
<td>Does it support data gateways?</td>
</tr>
<tr>
<td></td>
<td>Is it modular and flexible?</td>
<td>Does it support multimedia presentations?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Does it support case-based reasoning?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Does it permit prototyping?</td>
<td></td>
</tr>
</tbody>
</table>

The “most advantageous” action is the socially valid choice, which may or may not be the economically efficient alternative.

We adopt prototyping as a design strategy. Waterman (1986, p. 139) defines a demonstration prototype system as one that “solves a portion of the problem undertaken, suggesting that the approach is viable and system development is achievable.” This approach allows researchers to test ideas about the problem definition, scope, and knowledge representation. Langendorf (1985) argues that decision-makers often cannot specify their information needs in advance.
Prototyping facilitates understanding of the needs of the final system, allowing such requirements to become more precise and determinable (Wallace & Hurley, 1986).

Our guiding design principle is the central proposition advocated by Wiggins (Kim, Wiggins, & Wright, 1990). Systems designed to handle complex, data-intensive problems require the integration of a “combination of software components.” The prototype must integrate suitable information-processing technology and planning methodology with technical and social knowledge of the problem context.

We are in the process of further specifying and testing our design guidelines by applying them to a specific planning task and context. The prototype application must pass tests of need, complexity, and relevance. The candidate case needs to be both sufficiently complex and sufficiently relevant. There must be potential for refinement, and there must be a reasonable chance of making progress toward the next generation of applications. Disaster-mitigation policy analysis satisfies these criteria. Certainly, such an analysis is a complex-decision situation involving games against nature and games between persons.

Waterman (1986) characterizes prototyping in terms of:

1. main problems,
2. subproblems,
3. problem characteristics,
4. data,
5. important concepts, and
6. solutions (system outputs).

Stated in terms of Waterman’s approach, our research problem is as follows. The goal is the evaluation of damage-mitigation strategies for earthquake disasters. The main problem is to evaluate technical, economic, legal, distributional, and political questions regarding various earthquake-mitigation policies. The subproblems involve development of the appropriate system design for this type of knowledge domain (formalization of a methodology for integrating data of different quality from a variety formal and informal sources), reasoning under uncertainty, and evaluating and validating the system and its outputs. The problem characteristics are incomplete data, an unstructured problem domain, the difficulty associated with determining validity, and limitations on experts’ knowledge. The data involves technical data (urban stock, infrastructure, demographics, building and safety, earthquake science, etc.), economic data (construction costs, income groups, etc.) legal data (federal, state, and local earthquake law and building safety codes, political data on political actors affected, and constitutional and distributional questions. The important concepts are the behavior of different structures at different earthquake magnitudes, the valuation of the earthquake damage under status quo conditions, the valuation of the impact of new policies in reducing earthquake damage, the valuation of the private and public costs of policy instruments, the distribution of such benefits and costs across income groups and geographic (political) space, and the evaluation and validation of system outputs. The key problem elements are presented in more detail in Table 2.

Development of the prototype research and related research is ongoing, but some preliminary findings are available. The modelling system must be able to focus discourse on key variables. It follows that improvements in identifying these variables in the information base required for collective decisions will improve the rationality of these choices. The main cause of life loss, injury, and property damage associated with earthquakes is the collapse and failure of susceptible buildings located in unstable regions.

\(^{2}\)The City of Los Angeles Emergency Operations Organization (1990) identifies seven policy concerns with respect to earthquakes. These are: 1. a large number of damaged buildings and other facilities; 2. medical and psychological impacts; 3. loss of housing units and business locals; 4. economic losses by the public and private sectors; 5. hazardous geological conditions; 6. damaged roads, bridges, and utility systems; and 7. disruption of City operations.
<table>
<thead>
<tr>
<th>Problem element</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project goal</td>
<td>Develop an information and analysis system for the evaluation of local government policies intended to mitigate losses from earthquakes threatening Los Angeles.</td>
</tr>
<tr>
<td>Main problem</td>
<td>Determine damage-mitigation and distribution of net benefits associated with candidate policies. Evaluate technical, economic, legal, distributional, and political effects.</td>
</tr>
<tr>
<td>Subproblems</td>
<td>Formalize methodology for integrating data from a variety of formal and informal sources. Determine an earthquake’s expected damage. Determine the expected effects of candidate policies. Determine policy expected costs. Determine the distribution of expected net benefits across economic and geographic (political groups). Reasoning under uncertainty. Evaluating and validating the system and its outputs.</td>
</tr>
<tr>
<td>Important concepts</td>
<td>Expected earthquake damage under status quo conditions. Expected impact of policy on damage mitigation. Expected earthquake damage with policy in place. Expected net effects of damage-mitigation policy across economic and geographic (political groups). Validating system outputs.</td>
</tr>
<tr>
<td>Solutions (System outputs)</td>
<td>Distribution of expected net impacts by area, event, and policy. Distribution of policy expected net impacts by economic group, event, and policy. Distribution of policy expected net impacts by geographic group, event, and policy.</td>
</tr>
</tbody>
</table>

In the case of disaster mitigation, the policy analysis must identify both the efficiency and distributional questions by transforming the problem’s disorganized complexity into an ordered, transparent, and coherent representation. Ideally, policy-modelling efforts develop an ordered complexity that allows for the identifica-
tion of intervention points yielding the desired outcomes. Conflicts with, or avoidance of, the values and concerns of the larger community in which the plan is to be implemented renders such tools ineffective. Black-box modelling efforts do not appear coherent or transparent by decision-makers, though their developers may consider such models easy to use. The basic difficulty lies in the question, “Transparent or coherent to whom?” It is not enough that policy-evaluation tools be understood and accepted by the technical experts who construct them. These systems must inspire trust in the stakeholders defined by the contexts in which these systems are applied.

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