8-15-2013

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Recommended Citation
Alter, Steven, "Incorporating More System-Related Knowledge into Systems Analysis and Design," Proceedings of the Nineteenth Americas Conference on Information Systems, Chicago, Illinois, August 15-17, 2013

Incorporating More System-Related Knowledge into Systems Analysis and Design

Completed Research Paper

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ABSTRACT
This paper introduces a new, intuitively straightforward approach for thinking about important aspects of systems that are being analyzed, designed, and constructed. Building on past research highlighting metaphors related to organizations, IS, and projects, it shows how considering common, broadly applicable types of subsystems (not standard IS categories such as MIS and DSS) might provide direction, insight, and useful methods for analysis and design practitioners and researchers. A conceptual model identifies eight types of subsystems that are relevant to most systems in organizations. For each subsystem type, this paper identifies relevant metaphors, concepts, theories, methodologies, success criteria, design tradeoffs, and open-ended questions that could augment current analysis and design practice.

Keywords
Systems analysis and design, design metaphors, knowledge-based design

FROM METAPHORS TO SUBSYSTEMS

Systems analysis and design (SA&D) for information systems is associated with creating rigorously documented specifications of software/hardware configurations used by people or embedded within other objects. Emphasis on rigorous documentation increases the likelihood of creating high quality software, but may ignore important business, social, and conceptual issues that are relevant to SA&D.

This paper's focus on different types of subsystems emerged from an attempt to explore how metaphors might help in SA&D. The IS and organization literature contain a number of articles related to using metaphors for understanding complex, multi-faceted topics. *Images of Organization* (Morgan 1986) identifies seven metaphors for understanding organizations that go beyond the then-dominant organization-as-machine view: organism, brain, culture, political system, psychic prison, flux and transformation, and instrument of domination. Oates and Fitzgerald (2007) applies Morgan's images of organization in system development projects and provides 12 maxims for effective metaphor use. Winter and Szczepanek (2009) parallels Morgan (1986) by identifying seven images for projects in general: social processes, political processes, intervention processes, value creation processes, development processes, temporary organizations, and change processes. Kendall and Kendall (1993) identifies nine metaphors for IS development: journey, game, war, machine, organism, society, family, zoo, and jungle. These examples show that metaphors illuminate topics that might not be evident otherwise.

This paper identifies generic subsystems of most technical and sociotechnical systems as a way of identifying metaphors that can be used while analyzing, designing, and evaluating information systems and other systems in organizations. For example, instead of differentiating between MIS and EIS, we look at generic subsystems of both types of IS, such as informing subsystems and communication subsystems. Attention to metaphors at the subsystem level may help in identifying issues and concepts for SA&D. The basic approach is simple: Look at any IS or other subsystem of an organization and say, "Let's assume this is a communication system, a decision system, or a subsystem of several other types, and then let's see what types of issues we would look at and what would constitute success."

CATEGORIES OF ARTIFICIAL SYSTEMS AND SUBSYSTEMS IN THE IS FIELD

The subject matter of the IS field is artificial systems (Simon 1969) created by people through various processes. The conceptual model in Figure 1 identifies five types of artificial systems that are discussed in the IS discipline, plus eight common types of subsystems. (Figure 1 says that artificial systems of all five types consist of one or more subsystems; a particular type of artificial system may have subsystems of some types and not other types.) Building on a distinction between "system thinking" and "tool thinking" (Alter 2004), two system types on the left have human participants, whereas three on the right do not have participants but may have human users. We identify these system types to illustrate the broad relevance of the various types of generic subsystems that appear in the bottom row of Figure 1. If the purpose were different, a different taxonomy might be used.

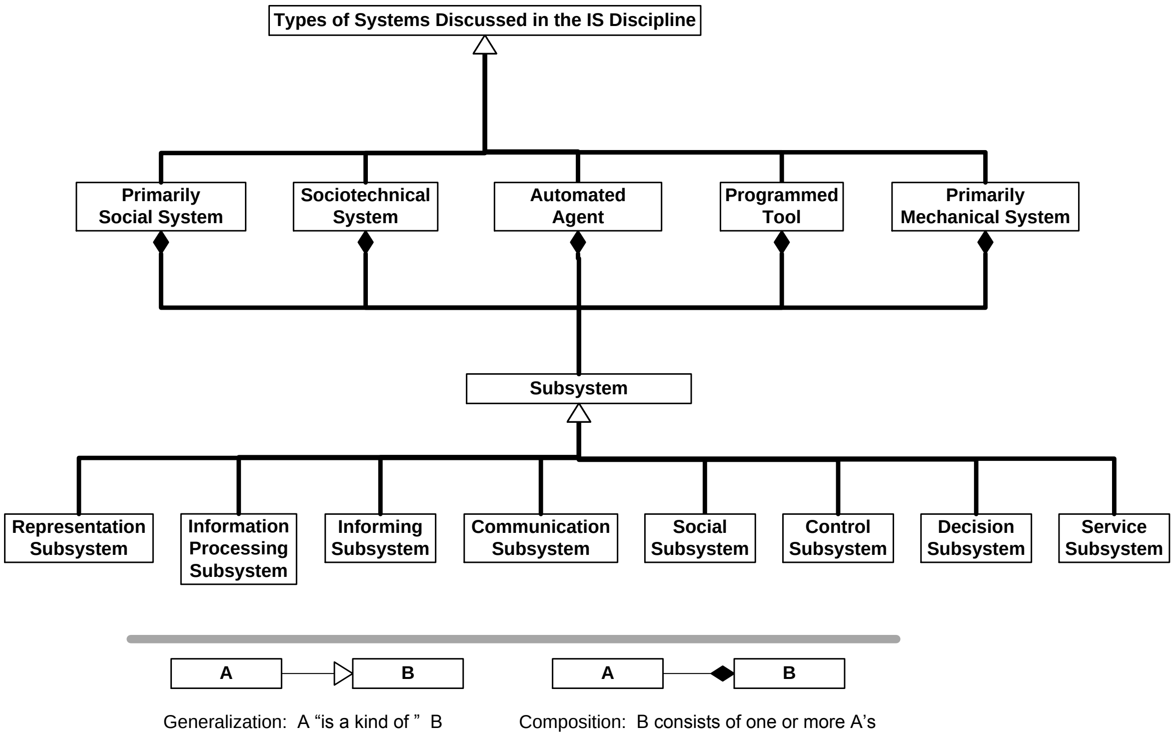

Figure 1. Conceptual model identifying broadly applicable subsystems

- **Primarily social systems** are systems whose operational activities and goals emphasize communication, collaboration, and relationships between people, and in which technology plays a relatively secondary role. Examples include corporate planning systems and cross functional steering committees. While technology can make such activities more efficient and effective, in many situations the primarily social aspects of the system are more directly related to outcomes.
- **Sociotechnical systems** are systems in which people rely on technology to perform work efficiently and effectively. Traditional views of sociotechnical systems subdivide them into a social system and a technical system (e.g., Mumford and Weir, 1979; Hirschheim and Klein, 1994). In alternative approaches, Alter (2008) includes social and technical elements within a work system view of information systems and Orlikowski and Scott (2008) propose sociomateriality approach in which the technical and social are viewed as inseparable.
- **Automated agents** are software programs that operate autonomously after being triggered by a condition or message. They perform tasks by executing programs to produce pre-specified outputs. They may subcontract work to other automated agents. Automated agents are systems because they contain components that operate together to perform work.
- **Programmed tools** operate through programmed capabilities that may or may not be controllable by users. Programmed tools of interest in IS include office software, models, the Internet, websites, and various types of hardware for processing information. As with automated agents, programmed tools are systems whose components operate together to perform work. Programmed tools may have human users or automated users (e.g., a web service used by another web service), but do not have human participants.
- **Primarily mechanical systems** include cars, airplanes, ships, buildings, electric power grids, and other devices and constructions whose main activities and goals are associated with physical or mechanical capabilities rather than information processing. Most important mechanical systems in today's world include embedded microprocessors and software. For example, a significant part of the cost of today's automobiles is related to embedded information processing subsystems built into engines, brakes, and other components.

Systems of some types typically contain systems of other types. For example, a sociotechnical system might contain one or more social systems; its technical components would likely contain one or more programmed tools. The purpose of identifying the different system and subsystem types is not to create hierarchies of concepts. Rather, consistent with

Skyttner's (2005) observation that a system is something to be recognized by an observer, the purpose of these distinctions is to promote insights by encouraging consideration of different aspects of a system or subsystem using knowledge that might have been overlooked.

Subsystems

The bottom section of Figure 1 identifies eight types of subsystems of the five types of systems. Capabilities and characteristics of subsystems of each type may have important impacts on the larger system's efficiency and effectiveness. In relation to SA&D, each subsystem type is associated with concepts, metaphors, and theories that are broadly relevant.

The subsystem types were selected based on the tradeoff between including too few and too many. Selecting too few subsystem types would have resulted in overlooking concepts and theories that frequently are relevant at the level of subsystems. Selecting too many subsystem types would have generated too many overlaps between the subsystem types. For example, a knowledge subsystem was not included because knowledge exists implicitly or explicitly in the other subsystem types and because subsystems that make knowledge explicit in the form of retrievable facts and documents can be viewed as information processing subsystems.

- **Representation subsystems** create representations of objects, phenomena, events, or other things of interest in a domain that is external to the subsystem. For example, an accounting IS applies accounting concepts and methods when capturing and summarizing information about objects and events in the world. Simulation models represent real or imagined situations. Image processing systems capture pixels (picture elements) representing a scene.
- **Information processing subsystems** perform a combination of seven elementary information processing activities: capturing, transmitting, storing, deleting, retrieving, manipulating, and displaying information.
- **Informing subsystems** provide information to users, ideally making the information truly usable. A typical example is an MIS reporting subsystem. Another example is an expert system's explanation module, which informs users about how specific recommendations were produced.
- **Communication subsystems** convey information between people and/or machines. Communication between machines occurs through messages based on pre-specified protocols for encoding, transmission, and decoding. Communication between people includes many situations in which information conveyed may be incomplete and unclear, transmission of messages may be garbled, and reception and interpretation of messages may be incomplete, inaccurate, or biased.
- **Control subsystems** use information to assure that activities or processes achieve goals or conform with rules of behavior. Introductions to control [sub]systems often use thermostats as an example of using information for control. Organizational control [sub]systems are far more complex because links between information and control-related responses are mediated by personal intentions, organizational culture, and many other factors.
- **Decision subsystems** perform, support, or automate activities related to making decisions. Decision subsystems that use little or no technology include periodic decision-oriented meetings that discuss tentative decisions. Decision subsystems that support decision-making include data- and model-based analysis efforts and analytical tools. Decision subsystems that automate decision-making receive inputs and use business rules, models, and other means to generate tentative or actual decisions.
- **Service subsystems** perform work for customers. The idea of service is used in vastly different ways in relation to service by people for other people, by software for people, and by software modules for other software modules. Service interactions with people call for attention to both stated and unstated needs and wants of customers, ideally based on understanding customers as people or organizations. The metaphor of service also calls attention to the customers' responsibility for creating value for themselves, with or without a provider's facilitation (Grönroos, 2011) Service responses for computerized entities call for unambiguous arrangements defining codes for signaling requests and for the content and form of responses.

The purpose of identifying subsystem types is not merely classification. The purpose is to identify and organize concepts, issues, and practical knowledge typically associated with each subsystem type. The next section will explain ways in which identification of subsystem types can help in analyzing, designing, and evaluating information systems.

We assume that subsystem types overlap, which is not a problem if each subsystem type draws attention to important concepts, issues, and knowledge. For example, information processing occurs within all other types of subsystems. Likewise, sociotechnical control subsystems typically include informing subsystems and decision subsystems; informing subsystems usually require a representation system and some kind of communication subsystem; and so on. An observer thinking about a system can try to identify subsystems of any type in Figure 1 and can use related concepts and metaphors for exploring issues that might be overlooked if an SA&D exercise places too much emphasis on documentation and too little on exploration.

Note also that successive decomposition of sociotechnical systems during detailed analysis and design efforts eventually isolates completely automated subsystems with no human participants (Alter 2010). Those automated subsystems may be of any of the types in Figure 1 except social subsystem. Similarly, analysis and design of sociotechnical systems may encounter each type of subsystem. Thus, concepts, theories, and methods related to each type of subsystem could help in finding and applying existing knowledge at various points as the analysis and design work unfolds.

SUBSYSTEM TYPES AS SOCIOTECHNICAL OR TOTALLY AUTOMATED SYSTEMS

Figure 1 identified two types of systems in which human participants perform work and three that are basically tools with human or automated users. Table 1 shows that almost every type of subsystem may be a sociotechnical system with human participants or a tool or automated agent.

Subsystem type	Subsystem type in the form of a sociotechnical system with human participants	Subsystem type in the form of a programmed tool or automated agent
Representation subsystem	People create a representation of reality. Example: performing financial analysis, news reporting, creation of month-end statements by accountants	Software creates a representation of reality. Example: Business intelligence software or search engine answers a query about reality.
Information processing subsystem	People capture, transmit, store, delete, retrieve, display, or manipulate data. Example: Researcher collects, filters, summarizes information and transmits it to headquarters.	Software captures, transmits, stores, deletes, retrieves, displays, or manipulates data. Example: MRI system, GPS system, RFID system, digital camera
Informing subsystem	People provide information upon request or on a periodic basis. Example: Employee submits a weekly progress report, meets with manager	Software provides information, either by subscription or on demand. Example: An internet-based news service provides a customized daily newspaper
Communication subsystem	People communicate with other people as part of collaboration. Example: Sales managers meet with production managers to discuss issues, problems, and tradeoffs.	Software transmits information from one location to another. Example: A large retailer's inventory management system transmits inventory usage data to headquarters periodically.
Social subsystem	People exert systematic effort to establish and maintain interpersonal and group relationships. Example: Sales department nurtures social relationships using periodic meetings and parties.	(None ... Relationships between software modules are not social.)
Control subsystem	Managers use information and incentives to motivate employees. Example: Department managers determine bonuses based on meeting targets and commitments.	Software uses business rules to control execution of processes. Example: Business process management (BPM) software enables the next step after a previous step completes.
Decision subsystem	People provide information that supports a decision process. Example: Marketing analysts produce market reports identifying problems and opportunities.	Software supports decision making or determines decisions automatically. Example: A marketing model calculates projections that help in decision making.
Service subsystem	People perform service work for other people, often co-creating value for their customers. Example: A physical therapist works with patients to hasten recovery after accidents	Software performs service responding to an unambiguous request through an interface. Example: A web service retrieves requested data from a remote server.

Table 1. Demonstration that sociotechnical systems with human participants and programmed tools used by people contain subsystems of almost every subsystem type.

USING SUBSYSTEM CATEGORIES IN ANALYSIS AND DESIGN

This paper shows how SA&D might be improved through organized consideration of different types of subsystems by incorporating concepts, theories, and methodologies that might otherwise be ignored. The following three tables are steps toward the elaboration and codification that could lead to incorporating subsystem types into formal SA&D methods. Table 2 presents metaphors and related questions for each subsystem type. Table 3 presents examples of broadly relevant concepts, theories, and methodologies for each subsystem type. Table 4 presents typical success criteria and design tradeoffs for each subsystem type. Each table summarizes ideas that could be explained in substantially more detail in a longer paper that could also present sample analysis templates using these ideas.

Metaphors Related to Subsystem Types

Table 2 identifies metaphors and related questions that can be used in relation to an entire system or any of its subsystems. The first column lists the subsystem types. The second column identifies a typical metaphor related to a subsystem type (e.g., newspaper, compass, or thermostat) along with several questions implied by that metaphor.

Subsystem type	A typical metaphor related to a subsystem type, plus questions implied by use of the metaphor
Representation subsystem	**Reflection of reality**: How good is this system's representation of reality? What does it emphasize? What does it ignore or downplay?
Information processing subsystem	**Factory for processing information**: How well does this system transform the right inputs into the right outputs at the appropriate quality level? What can be done to improve efficiency and consistency and reduce errors, cycle time, and downtime?
Informing subsystem	**Newspaper or news website**: How well does this system convey information that is of value to system participants or customers? How well does it provide the breadth and depth of information that participants or customers need or want?
Communication subsystem	**Delivery mechanism**: How good is the organization and clarity of information within this system? How well does this system communicate information? In what ways is the information clear enough, complete enough, and timely enough? Are there problems with formulating or interpreting information?
Social subsystem	**Social club**: How healthy are the social aspects of the system? How well do the social aspects of this system create and maintain social relationships that promote comfort, cohesiveness, and friendship?
Control subsystem	**Thermostat**: To what extent does this system's control apparatus use appropriate information to keep the system focused on its goals? Do the control aspects of the system encourage or discourage the use of judgment or attention to tradeoffs that are important for both efficiency and effectiveness?
Decision subsystem	**Compass**: How well do the decision-oriented aspects of this system provide direction for making appropriate decisions that recognize tradeoffs between the importance of the decision, the potential quality of the decision, the relevant ethical considerations, appropriate attention to risk, and the amount of time and effort devoted to making the decision?
Service subsystem	**Customer advocate**: How well does this system recognize and respond to customer wants and needs? Does it allow or encourage appropriate customer participation in the co-creation of value for customers ?

Table 2. Metaphors and related questions for each subsystem type

Concepts, Theories, and Methodologies Related to Subsystem Types

Associated with each subsystem type are concepts, theories, and methodologies that can be applied in SA&D and in research about systems in organizations. Table 3 lists a subset of the concepts, theories, and methodologies that are relevant for each subsystem type, thereby illustrating that conscious consideration of the subsystem types in either research or practice could be amplified by existing knowledge that might not otherwise be considered. Many other theories are relevant to each type of subsystem, and might have been mentioned in a longer table. Also, Table 3 does not distinguish between sociotechnical and programmed tool subcategories within each subsystem type. Future research could explore that distinction by identifying concepts, theories, and methodologies that are especially relevant to sociotechnical versions or programmed tool versions of each subsystem type.

Subsystem type	**Typical concepts (Each may apply for sociotechnical systems and/or programmed tools)**	**Examples of potentially relevant theories or methodologies**
Representation subsystem	Entity, event, state, inclusion, exclusion, filtering, summarization, precision, bias, characteristic, measure of performance	• Conceptual modeling methods • Bunge-Weber-Wand (BWW) ontology • OntoClean methodology (Guarino and Welty, 2002; 2009) • Actor network theory
Information processing subsystem	[nouns] entity, relationship, data item, class, method, object, event, state, process, pre-condition, post-condition, business rules, [verbs] capture, transmit, store, delete, retrieve, manipulate, display, initialize, initiate, back-up, update	• Entity relationship diagrams • Data flow diagrams • Flow charts, activity diagrams • Object orientation • Unified modeling language (UML) • Structured systems analysis and design
Informing subsystem	inclusion, exclusion, accuracy, conciseness, focus, filtering, outlining, textual vs. graphical presentation, types of graphical displays, cognitive capabilities and limitations, personal style related to information usage, information overload, measure of performance	• Infological equation (Langefors,1973) • Information presentation theories • Value of information • Human information processing theory • Information theory • Theories of reading comprehension
Communication subsystem	Messages, utterances, encoding, transmitting, decoding, interpreting, communication channel, wired, wireless, signal-to-noise ratio, attenuation, understanding, one-way or two-way	• Language action perspective (LAP) • Social network theory • Rich media theory • Hermeneutics
Social subsystem	Organization, group, member, relationship, connection, hierarchy, status, authority, role, division of responsibility, group culture, cohesion, formality, cooperativeness, trust	• Organization theory • Group psychology • Social network theory • Ethnographic methods
Control subsystem	Goal, evaluation method, evaluation criteria, positive and negative feedback, linearity and non-linearity, rationale, business rules, chaotic behavior, informal vs. formal feedback	• Transaction processing controls • Business process management (BPM) • Feedback control systems • Chaos theory
Decision subsystem	Decision, criteria, alternative, value, risk, payoff, utility, utility function, tradeoff, projection, optimum, satisficing vs. optimizing, heuristic, probability, distribution of results	• Decision analysis • Decision trees • Simulation • Optimization
Service subsystem	Customer, provider, customer value, co-creation of value, price, cost, service-orientation, customer-focus, customer-centricity, service interaction	• Customer satisfaction theories • Service-dominant logic • Service-oriented architecture • SERVQUAL

Table 3. Examples of concepts, theories, and methodologies for each subsystem type

Success Criteria and Design Tradeoffs Related to Each Subsystem Type

Table 4 shows that each subsystem type suggests a series of typical success criteria and design tradeoffs. Some of the criteria and design tradeoffs are common to most systems, but others are mostly associated with specific subsystem types.

Subsystem type	Typical criteria for success	Typical design tradeoffs
Representation subsystem	Quality of representation: completeness, accuracy, clarity. Limitations of representation: bias, omission, confounding	• Precision/ granularity vs. big picture issues and understandability. • Focusing on objective data that can collected automatically vs. reflecting reality more fully by including subjective information.
Information processing subsystem	Efficiency, cost, accuracy, precision, error rate, rework rate, downtime, vulnerability	• Cost and efficiency vs. completeness and level of detail. • Focusing on processing information, but ignoring the meaning or accuracy of the information.
Informing subsystem	Information quality, completeness, usefulness, timeliness, accuracy, understandability, comparability, bias	• Informing vs. under-informing or over-informing. • Information overload • Focusing on informing, but ignoring human biases and human abilities to retrieve and process information
Communication subsystem	Clarity, understandability, conciseness, accuracy of the perception of a message, extent of empathy and warmth, signal to noise ratio	• Insufficient vs. excessive communication • Richness of multiple communication channels vs. confusion about which ones to use when. • Focusing on communication, but ignoring the impact of the communication
Social subsystem	Cohesiveness, openness, comfortableness, empathy, extent of genuine inclusion	• Sociability and comfort vs. task focus and accomplishment. • Democracy vs. hierarchy
Control subsystem	Extent and duration of deviations from goals, delays, cost of monitoring and correction, likelihood of overshooting control targets	• Control vs. micromanagement of people. • Quick responsiveness vs. instability. • Focusing on control targets vs. minimizing negative impacts on participants or customers • Excessive monitoring vs. increased risks of non-compliance
Decision subsystem	Quality of the decisions in terms of outcomes, riskiness, participation, concurrence, ease of implementation	• Quick responsiveness vs. superficiality. • Complexity and precision of models vs. understandability • Brevity vs. omission of important details
Service subsystem	Service quality, efficiency, production cost, total cost to customer, customer satisfaction	• Customer comes first vs. provider comes first. • Placing activities front stage vs. back stage. • Customized vs. commodity service methods.

Table 4. Typical success criteria and design tradeoffs for each subsystem type

BRINGING SUBSYSTEM CONCEPTS AND METAPHORS INTO SYSTEMS ANALYSIS

Consider a systems analysis checklist or analysis tool that would help analysts explore issues beyond the content of use cases, activity diagrams, and typical summaries of problems, processes, information, and constraints. Table 5 shows a starting point for that type of tool. The analysis would consider the scope and content of each type of subsystem within the system being analyzed. The tool or checklist could provide typical open-ended questions and follow-on questions that could lead to deeper situational understanding.

The questions in Table 5 are straightforward and can be pursued without deep theoretical knowledge in each area. Many are surely pursued in some way in current systems analysis efforts. Using something like Table 5 might reduce the likelihood of overlooking many important issues. A possible application in research takes the form of a checklist to identify types of issues that were pursued or ignored in real world settings.

Pre-specified templates related to theoretical concepts in each area might go much further. For example, when thinking about decision subsystems, relevant questions might use concepts such as utility functions, risk tolerance, and local vs. global optimality. Inclusion of concepts such as those in the analysis of bank information systems might have generated interesting warnings during the recent financial crisis. Whether or not those warnings might have been taken seriously is a different question that raises other issues about espoused purposes of information systems versus their purposes in practice.

Subsystem type	Typical open-ended questions, plus follow-on questions
Representation subsystem	Open-ended question: What are examples of important information that is not represented well in the information system or is simply absent? ... Follow-on questions: Is the information recorded outside of the formal IS on spreadsheets or on paper? Does the information system record information in ways that require manual workarounds? What is the impact of those workarounds?
Information processing subsystem	Open-ended question: Are there situations when the information system is ineffective for capturing, transmitting, storing, retrieving or manipulating important information? ... Follow-on questions: What information is captured inaccurately? What information is difficult to store or retrieve? What information would be more useful if it could be refined further through calculations or visual display?
Informing subsystem	Open-ended question: How does the information system tell managers what is going on? ... Follow-on questions: When a manager wants to figure out what is going on, what information is only available through other sources, including face-to-face? What information that should be part of the information system is missing or difficult to obtain?
Communication subsystem	Open-ended question: In what ways does the information system help people communicate with each other? ... Follow-on questions: When is information garbled in communication? Are there areas where inadequate communication of information from one location to another causes problems? Where does inappropriate communication cause problems?
Social subsystem	Open-ended question: In what ways does the information system help in maintaining social relationships within the organization or with customers? ... Follow-on questions: Does the information system ever interfere with social relationships? How would it be possible to use the information system to strengthen social relationships and cooperation?
Control subsystem	Open-ended question: How does the information system help the organization meet its targets? ... Follow-on questions: Does the information system ever produce information or reports that are misleading or that cause management or execution errors? How might the information system be more effective in meeting organizational targets?
Decision subsystem	Open-ended question: How does the information system help in making important decisions? ... Follow-on questions: What decisions are made with incomplete, inaccurate, or outdated information? How might better information help in making decisions? Where would that information come from?
Service subsystem	Open-ended question: How does the information system help people perform service for internal or external customers? ... Follow-on questions: Does the information system help in clarifying what the customer really wants or needs? Does the information system make it easier for customers to co-produce the service by taking responsibility for aspects of service activities? Does the information system help in achieving the right balance between what the customer sees versus what only the provider sees?

Table 5. Open-ended questions based on subsystem types

CONCLUSION

This paper proposes using subsystem types to exploit existing knowledge by highlighting issues that are barely visible in typical SA&D methods. Each subsystem type brings metaphors, analytical concepts, design criteria, theories, and performance metrics that might be overlooked if the analysis focuses primarily on identifying problems and documenting details. Trying to identify subsystems of each type within a system and scanning tables of frequently relevant metaphors, concepts, and design criteria might reveal insights that would otherwise be overlooked.

I am not aware of any past attempts to explore the use of subsystem types within suggested thought processes in systems analysis and design. A literature search found no such attempts. Consideration of subsystem types differs from consideration of types of IS (e.g., TPS, MIS, DSS,) or of metaphors related to organizations and projects. Tables in this paper illustrate why subsystem types seem more useful and suggestive of key issues than categories of IS or metaphors for organizations or projects.

Introduction of these ideas obviously does not guarantee they will be used successfully in SA&D. However, prior theorizing about metaphors for organizations and projects and initial research that applied metaphors in real world settings (e.g., Oates and Fitzgerald 2007) supports the possibility that subsystem types and related metaphors, concepts, criteria, tradeoffs, and theories might be useful in practice and in research. A practical feature of this approach is that it can be used independent of formal systems analysis or in conjunction with existing SA&D methods by simply adding new questions of the following form: "Assume that this system or subsystem is of type X (among the eight types identified). Which common issues should I consider, and what concepts, theories, methods, success factors, and design tradeoffs should I pay attention to?" Those questions could be posed at whatever level of brevity or depth is appropriate. While non-experts in areas such as communication, decision making, and control systems would apply the relevant knowledge less precisely and less deeply than experts would, raising aspects of those topics through simple open-ended questions such as those in Table 5 would be more beneficial than ignoring them altogether.

The IS discipline and related disciplines have generated a substantial body of research results related to topics that are barely mentioned in typical SA&D methods. Straightforward application of ideas summarized in Tables 1 through 5 could make more of that knowledge available for analysts, designers, and managers without disrupting the benefits of existing methods.

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