Social Engineering

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Abstract

People and organizations are significantly *affected by the computer systems they use. When people procure or build systems they hope the effect will be positive, but the result has been negative in a large number of cases, such as the well-documented London and Melbourne Ambulance Systems. LAS and MAS were not capable of performing their prime function because the system was not designed to properly support the organization. Use of methods identified in this paper during concept exploration and design phases would have revealed many of the problems before they occurred.*

1. Introduction

Understanding risks in introducing computer systems into an organization, together with risk monitoring and mitigation, would provide significant improvement in an organization's satisfaction with the computerized systems it builds or procures. During concept exploration, organizations would use methods that forecast the effect of computer systems on organizations. During system development, analysts would use the methods to identify detailed features and variables that could have a significant effect on an organization, and to identify the user, organization, or process these system features and variables would affect. During system operation, organizations would use the methods to better understand the effect of the system on the organization, and needed changes. Used over time, such methods could lead to a better understanding in industry of the cause / effect relationship of computer systems on organizations.

Researchers are developing detailed workload models to better understand human capabilities and limitations when these humans are working with, or are a part of, an existing complex system [Martin et al. 01]. The ability to predict human and group performance when interacting with a proposed system should prove at least as valuable as there have been a significant number of failures where computer systems have not improved organizational effectiveness. Examples of such systems are well documented by Dalcher and include the Melbourne Ambulance System where the volume of information caused the system to bog down, consoles were locked up for too long based on not understanding the time it took to allocate a vehicle to a job, and automatic route identification did not support driver needs, resulting in lost control of essential services and death [Dalcher 01]. Had the system developers examined critical variables, the problems might have been avoided. The system was built to improve the time from a call for an ambulance to patient pickup. Critical variables are rate of answering calls, rate of assigning ambulances, time for driver to locate the patient site and the route, and time for the ambulance to get from its present location to the site. Had the system developers understood all the factors that influence these variables, the risks might have been reduced. Use of the methods presented in this paper could provide this data.

Organization models have to address human and team cognitive processes, as knowledge work is primarily cognitive. For example, the organization assigning ambulances to jobs has to decide which ambulance to assign and the driver should determine the route. Both decisions can be computer-assisted.

Situation-assessment and decision-making is a complex cognitive task that is an integral part of most organizational processes. Organizations must understand the variables that affect specific decisions and the required situation awareness and timing it takes to make a good decision. For this reason, we developed a model of situation assessment and decision-making and evaluated process models to determine which models would best support organizational understanding of situation assessment and decision-making and the effect of computerized support. Such a model has to address numerous variables and their inter-dependencies, and should encourage system development stakeholders to brainstorm and think "out of the box".

We based our situation assessment and decision-making model on existing models of human behavioral cognition, workload, and task demand [Bloom 56; Wickens 92; Rasmussen 94]. We also incorporated work on mental models and their impact on team situation assessment [Cannon-Bowers et al. 96]. We based our process-modeling paradigm on proven theories of process modeling.

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2. History of process modeling

To forecast the effect of computer systems on organizations, it is necessary to understand and document appropriate aspects of the organization's process. In the early 1990's, a new research area emerged called *process modeling*, which was primarily used to describe software processes. This research has been adapted for modeling organization processes.

Process modeling is distinguished from other types of information system modeling because process modeling provides the capability to model the role of humans in the process. Research in process modeling was motivated by several factors: a) traditional modeling techniques cannot adequately capture the multi-person, largely intellectual design activity with a high degree of cooperation, distribution, and coordination of various tasks, b) intellectual products undergo continuous modifications and thus the development process is evolutionary in nature, c) decisions change rapidly as awareness and technology change. [Rozenblit and Kocourek 97, Armenise 93, Curtis et al. 92].

Process modeling applies to business process reengineering, which is the "fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance such as cost, quality, service, and speed" [Hammer and Champy 93]. Business process reengineering normally includes computer support.

A process is a "partially ordered set of steps intended to reach a goal" [Curtis et al. 92]. A process includes notions of:

1. Agents, which are human or machine elements (actors, methods) that carry out process phases.
2. Roles, which are a set of process elements assigned to an agent. A role is a unit of functional responsibility.
3. Artifacts, which are objects or products created as a result of enacting a process phase or element.

Traditional approaches to represent, plan, and optimize processes stem from methodologies that have emerged over the years in the operations research and computer science disciplines. The techniques have a goal of generating a process that will optimize a set of certain criteria such as minimizing cost or maximizing resource utilization. Frequently, the optimization goal is replaced by the goal of achieving a satisfying solution, especially in the presence of multiple criteria.

3. Terminology in process literature

To understand and evaluate process-modeling methods, a standard vocabulary is needed. While terminology is not always consistent in process modeling literature, the terminology in figure 1 is representative. Process terms are identified by rounded rectangles. Associations between terms appear on the lines connecting the terms. Words above or below the rectangles define alternate terminology.

A process consists of methods that control a series of actions or activities intended to reach a goal, possibly resulting in products. Methods and standards constrain a process, by controlling activities, products, tool development, and tool interfaces.

Teams perform the project. A team is a type of agent, and contains team members, that are also agents. Agents are active resources, as opposed to materials that are passive resources. Each team member plays one or more roles, for example developer or manager. Activities are performed by team members, each playing one or more roles. The role supports the activity. Activities produce products, aided by tools, and controlled by methods. In process modeling literature, products are called artifacts. Methods, activities, artifacts, and tools can be grouped into classes, where all members of a class share common properties. Examples of activity classes are engineering and operational, where engineering activities develop the system and operational activities carry out a mission using the system. Examples of artifact classes include documents, measurements, models, systems, and so on.

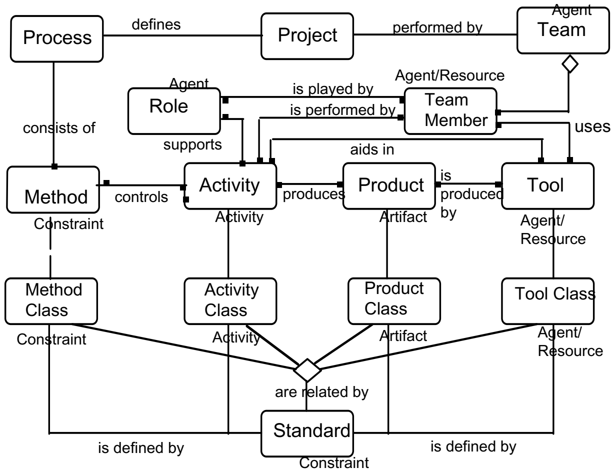

Figure 1. Associations between process terms.[1]

People in organizations can play a functional and an organizational role as in Figure 2. Functional roles describe the task the user is performing, for example: leading a team, facilitating a meeting, documenting a specification, and so on. Organizational roles are titular. These roles identify the organization of which the person is a member and their title. For example Joe is the Project Manager, in charge of building the XYZ ship. Ned is a

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[1] Adapted from [Voss 94]

member of the Project and is on the Ship Replenishment Integrated Product and Process Team (IPPT).

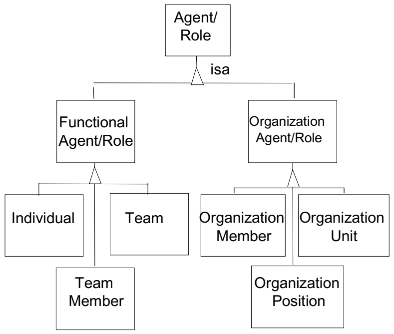

Figure 2. Entity-relationship diagram defining human agent relationships

4. Models of discrete-event behavior

We recommend state machines for modeling detailed process behavior [Harel and Gery 97] over activity networks [Nilsson 80], hypergraphs, [Nilsson 80, Rozenblit and Kocourek 97], and Petri-nets [Bretschneider 1993]. State machines appear to have the best combination of comprehension and formalism. State machines are widely used for modeling required functions and are recommended for process modeling [Armitage et al. 94, Raffo 96]. State machine models can be simulated and analyzed for reachability, deadlock, and the ability to enter an undesirable state, are easier to understand than Petri net representations, and can be automatically translated to Petri nets for analysis. State machine representations model states, transitions between states, events that cause state transition, and actions that result from the state/event occurrence. State machines support critical and optimal path analyses. In a state machine, the change from one state to another is called a transition. Transitions occur due to an event, a system condition, or an event occurring when a condition is true.

Military Specification, Human Engineering Requirements for Military Systems, Equipment and Facilities [MIL-H-46855] identifies human functions that military systems must support, such as decide, develop, communicate, receive, transmit, delay, inspect, monitor, approve/disapprove, perform, plan. State machine representations support the performance of these functions within states or on state transition.

The Extend discrete event process model is time and event oriented [Hansen 97, Extend Web Site]. This model is useful when the process is well understood. A discrete process is one in which process steps occur when a need arises, such as the completion of a task, the expiration of some time unit, a decision etc. Items or objects flow through the simulation, which is used to determine process measures, such as utilization of staff, cycle time, and process throughput.

Objects in a discrete event process simulation are assigned attributes that are used to model cycle time, cost, errors, etc. These attributes represent the type of objects flowing through the model, the size of the objects, and so forth. The object carries the attribute, such as the cost of the object, as it flows through the system. After each step, the cost of that step is added to the cumulative cost of the item. If there is rework associated with the item, the entire cost of the item is accumulated, and at the end of the simulation, we know the accumulated cost for each item

5. Models of continuous behavior

This type of model is used to model situations that are not controlled by events, but rather happen in smooth increments of time. Such models identify the relationship in system variables and the rate of change in system state. Such models are valuable for high-level decision-making, e.g. how many personnel to hire and how fast to bring them onboard. Equations relate the variables, e.g. the rate of hiring new personnel, the time used by experienced personnel to train new personnel, and the amount of work performed over a specific period of time. Such simulations are used in process engineering to determine the relationships between business or engineering drivers, those factors that affect the viability of the project.

One example of such a model is System Dynamics, [Forrester 68, Abdel-Hamid and Madnick 91, Abdel-Hamid 96, Ithink Web Site]. We are proposing to use System Dynamics to (1) brainstorm about system variables that affect organization decisions in positive and negative ways, and (2) forecast the effect of systems on humans and organizations. System Dynamics expresses and simulates the dynamic relationships in feedback systems, which may consist of human and physical parts [Forrester 68]. Since we are interested in the effect of systems on dynamic organizational behavior, we focus on interactions within the closed boundary that consists of the system and organization. System Dynamics flow diagrams provide insights as they provide an abstraction and give a broader perspective than the more detailed equations for which they provide an abstraction. Flow diagrams consist of interconnecting feedback loops. These feedback loops help us understand system effects of “auxiliary variables” on “level variables” such as the level of user knowledge or the level of user attention (to a monitored screen). Since there is feedback, the auxiliary variables may also be a function of the level variables. Level variables are state variables that describe the condition of the system at any point in time. They are calculated based on given values of auxiliary variables, and because there is feedback, the previous value of the level variable.

Rate variables define how fast level variables are changing. Whereas the levels represent the system state, the rate variables represent decisions (or actions). A rate equation explains how a decision stream is generated. It is an algebraic expression that identifies the current rate of change in terms of the current information (or state). Organization and system information that exists at a point in time is the basis for the decision made at that moment. The decision controls action. Over time, the stream of information affects the sequence of decisions, affecting the stream of actions.

When system action stops, the level variables still have values and can be observed. The rate variables cease when system action stops, and cannot be observed. However the average rate of change is a level variable, and can still be observed.

For example, auxiliary variables, Desired Inventory (a goal) and Inventory Adjustment Time (a time period) are inputs to the Inventory Order Rate, which increases the Inventory Level. Changes in the Inventory Level (both positive and negative) also affect the Inventory Order Rate (feedback). That is, the discrepancy between Inventory and Desired Inventory, together with the Adjustment Time, affects the Inventory Order Rate. Other variables such as Available Supply and other feedback loops such as that involving Sales also affect Inventory. The rate equation (in this case the Inventory Order Rate equation) is an organization or system policy.

6. Integration of models

The way one chooses to describe systems can determine in a subtle way what questions one asks and the phenomena to which one pays attention [Umpleby]. To ensure that the correct phenomena are investigated, analysts should model organizations interacting with the proposed system using multiple views, as follows. Integration of detailed discrete event simulation and macro level continuous simulation could yield powerful forecasting methods.

- Activity behavior is modeled as hierarchical state machines, based on the method used in the Statemate tool [Harel 87]. This model has been shown to provide excellent support for process modeling [Armitage et al. 94, Raffo 96].
- Resource models define human, machine, tool, and facility resources. Resource behavior is defined using hierarchical state machines. Individuals (agents), skills, organization elements, and non-human resources are assigned to activities.
- The Product model defines all process products, such as system and support items, services, knowledge, and documents. The product model defines the number and type of elements that constitute each product. The model specifies alternate elements where required.
- Inter-activity information flow is defined in the Information Flow model, which is based on the Data-flow model. Knowledge, documents and other products are output from activities and are used by other activities. Since human resources are assigned to activities, one result of model analysis is the degree and content of communication among human players.
- The Organization view of the resource model supports the Integrated Product Team (IPT) approach.
- The effect of the system on individual and organizational users is modeled using System Dynamics.

7. Modeling the human in the system

To determine how systems affect organizations, it is necessary to model cognitive processes. In 1956, Benjamin Bloom classified six levels of learning into a hierarchy that has become known as Bloom's Taxonomy [Bloom 56]. Requirements for cognitive performance on the part of the learner, increasing as one moves through the taxonomy, start with recall and end with evaluation. Each level in Bloom's Taxonomy involves the use of a key cognitive process. Recall involves learning pieces of information, such as facts and definitions, so that you are able to repeat them, and requires cognition at the level of information processing. Comprehension requires understanding enough about a topic so that you are able to explain it to someone else, and requires the cognitive process of critical thinking. Application involves putting what has been learned into practice and applying what you know. Application requires higher order critical thinking. Analysis involves breaking a topic into specific parts and studying the interaction of the parts, which requires problem solving. Synthesis involves integrating prior knowledge and creativity to gain insights into a topic, and requires the cognitive process of research. Evaluation involves knowing a topic so well that you can judge its quality according to established criteria, and requires the cognitive process of assessment.

Rasmussen also defined a framework to classify types of situation assessment and decision-making [Rasmussen 93]. Tasks are classified as detection and activation, data collection, situation evaluation and priority setting, activity planning, execution, monitoring, and verification of plans and actions. Rasmussen classifies task performance at three levels: skill-based, rule-based, and knowledge based. Skill based behavior occurs without conscious thought. Rule based behavior occurs in familiar work situations, and follows a stored rule or procedure. Operators are aware of alternate choices of actions and make choices among them. Knowledge based behavior involves formulation of goals. The operator has a mental model of his environment. Plans of action are tested against goals.

Wickens' model of information processing is composed of critical stages of information processing: (1) short term sensory storage of receptor information, (2) perception, decision and response selection, and (3) response execution [Wickens 92]. Stage one does not need conscious attention, has a very short time span, normally less than ten seconds, and the information decays rapidly. Stages two and three are supported by working and long-term memory. Each stage of processing transforms data and consumes time. Memory resources, information decay, and capability to perform actions in rapid succession, and simultaneous use and speed of processing resources limit human activity.

Based on this and other work, Owens defined a model of Situation Assessment and Decision Making [White et al. 98]. Figures 3 and 4 represent aspects of this model in Dataflow Diagram (DFD) and State Transition Diagram (STD) format.

Owens proposed four classes of variables that can affect situation assessment and decision analysis. These include individual variables, task variables, environmental variables and organizational variables. Individual variables can be psychological or physiological. Psychological variables include lack of experience, lack of knowledge or expertise, lack of confidence in information, lack of flexibility or adaptability, lack of risk management ability, and lack of motivation to perform. Physical variables can include fatigue from sleep loss or work-rest cycle demands.

Task variables include task criticality demands, task workload demands, time stress demands, cost to acquire additional information (in terms of fiscal cost, time, or human resources) and consequences of decisions (including a delayed decision, no decision, or error). System variables include information quality, quantity, and integrity, and productivity enhancement. Environmental variables include noise and other distractions such as lighting, heat, and cold. Organizational variables include cost containment demands, schedule demands, regulations/policy demands, lack of manpower/team members, consequence of decision on others, poor communication within group, and poor interactive team skills.

Internal and external effects resulting from decisions and resultant actions can affect future situation assessment.

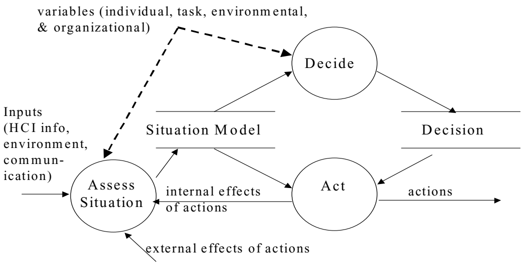

Figure 3. Situation assessment and decision-making process, data flow diagram

Situation Assessment consists of Perceiving, Comprehending, and Projecting Future States, which occur continuously and in parallel (see figure 4). Situation Assessment leads to Situation Awareness, during which a person's mental model is equivalent to the Situation Model in figure 4.

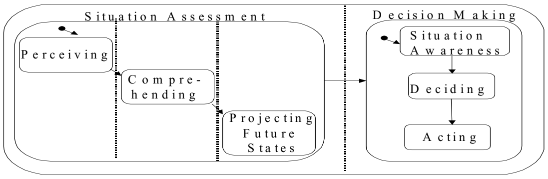

Figure 4. Situation assessment and decision-making process, state transition diagram

8. High level system dynamics model of situation assessment and decision-making

Figure 5 shows a pattern for using System Dynamics to model the effect of system variables on situation assessment and decision-making. This figure is generic, and would be tailored for each organizational decision. The model in figure 5 illustrates the feedback loop relating situation awareness, the level of risk in decision-making, the actual system or organization state, and available information about the system or organization state.

At the start of model execution, the System or Organization State is defined at a specific level. For example, the organization is undermanned by 10%. Based on being undermanned, the Level of Information about the actual System or Organization State might be less than perfect. This would be affected by such variables as fatigue from overwork, lack of motivation from having to take on the responsibility of others, task workload demands, time stress demands, cost in time and human resources to acquire additional information, schedule and policy demands, poor communication due to workload demands, and environmental distractions such as applying for other job positions.

If the Level of Information about the actual Organization State is insufficient, Situation Assessment will reflect that. Situation Assessment is affected by the above variables, as well as individual psychological variables such as lack of experience, lack of knowledge, lack of confidence in the information, lack of adaptability, and lack of communication skills. Variables describing computer-aided support, such as the quality of the information display, and the quality, quantity, and integrity of information in the system will also be factors in Situation Assessment. The Level of Risk in Decision-Making will be dependent on Situation Awareness and also on other variables, such as the consequence of a delayed decision, no decision, or erroneous decision. The Level of Risk in Decision Making results in actions that affect the System or Organization State. The model is executed iteratively to determine the impact of different variables on the Organization State.

9. Using process models

After building process models, engineers should prove that the model works for a similar existing system prior to model usage. It is only in this manner that they build confidence in the model. During model usage, the model should be periodically verified as the system or organization process, and factors affecting that process, may change. Engineers restructure the model until model inputs ask the correct questions. They verify data characteristics, such as individual, environmental, task and organizational variables, and time related variables.

Had those responsible for the LAS system used process models that reflected reality, and collected appropriate and accurate data, they would have found that the number of calls could overload the system, and that the time from a call for an ambulance to patient pickup would be longer than anticipated. They should have found where the process and resources were inadequate. They could have determined at what point the system would fail, and planned how to avert failure.

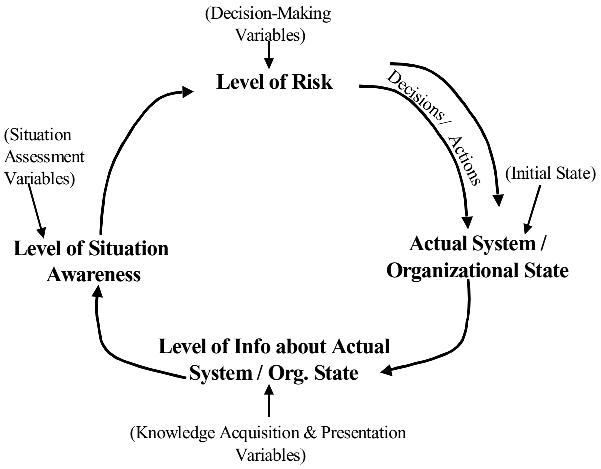

Figure 5. System dynamics model, variables affect situation assessment and decision making

10. Conclusions and future work

This paper identifies methods, which would benefit stakeholders in building computer-based systems that support their organization. The paper models the human situation assessment and decision-making process. A situation model was defined to be equivalent to situation awareness and to represent the current state of knowledge that a human / agent / organization possesses concerning elements in a dynamic task environment. It is well known that human situation assessment and decision-making can be affected by numerous internal and external influences. A set of variables was incorporated into the model, which can act internally or externally to affect situation assessment and decision-making in agents and teams.

Future work will (1) further delineate the System Dynamics model for Situation Assessment and Decision-Making (2) integrate methods for modeling Situation Assessment & Decision Making, and (3) analyze the effectiveness of described methods in predicting the effect of automated systems on social organizations. The list of variables that affect situation assessment and decision-making will be extended during this work.

Over time, process modeling methods should lead to better understanding of the impact, both positive and negative, that a computer system will have on people and organizations.

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