TOWARDS AN INTEGRATED C3I FRAMEWORK FOR HUMAN PERFORMANCE MODELING AND ANALYSIS

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ABSTRACT

This paper describes an effort to develop an analysis framework and computer-based tools for assessing the impacts of materiel, personnel, and organizational changes in the military intelligence (MI) production system. The framework is intended to assist the MI community in meeting commander's intelligence requirements of the future. A low resolution technique that facilitates the evaluation of intelligence effectiveness based on an error framework was adopted to develop a series of representational models: conceptual, performance, and information quality. Their integration resulted in the Intelligence Production Model (IPM). In an effort parallel to the development of the IPM, a classical, network-based, task-flow model of soldier tasks (eg. listen, record, monitor, estimate impact and decide, etc.) was constructed. The integration of the two models is a step towards a comprehensive C3I (control, command, communication and intelligence) battlefield research environment that will allow us to explore consequences of various operational scenarios, different configurations of technology, assignments of functions, and roles in the MI systems.

1 INTRODUCTION

Military Intelligence (MI) production is a complex, multi-faceted system that integrates hardware, software, and human components. At a high, conceptual level, such a system can be viewed in terms of the "input-process-output" relation (Burnstein 1991) . This relation establishes how intelligence results as an output from the production process given input data. Modeling MI production provides an introspection into the performance aspects of such a process and a means of assessing the impacts of change in intelligence production on the overall organizational effectiveness. In addition, credible models of the process can be used as an effective training tool.

Whereas relatively well established methods exist for modeling the technology-based elements (eg. electronic intelligence gathering components), capturing the human information processing and analysis is a complex and intangible process. Thus, rather than develop a holistic, all encompassing process model, Burnstein and (1991) proposed a low resolution technique that facilitates the evaluation of intelligence effectiveness based on an error framework. This framework was the basis for the development of an integrated Intelligence Production Model (IPM) that models the system that produces predictive intelligence, ie. forecasts the enemy coarses of action.

In an effort parallel to the development of the IPM, a classical, network-based, task-flow model of soldier tasks (eg. listen, record, monitor, estimate impact and decide, etc.) was constructed (Wojciechowski and Knapp 1999) . This model, called C2V and implemented in MicroSaint™ (Micro Design and Analysis 1998), provides typical summary data such as operator utilization, task throughput, task average processing time, number of tasks performed, etc. These measures give introspection into the efficiency of human operators in an MI setting. However, in assessing the human performance in intelligence production, a broader set of questions need to be addressed. More specifically, given a scenario and a set of operational conditions, sample questions may include: "Who is overloaded or underutilized at various points in time?", "What are the bottlenecks in terms of tasks dropped?", "What is the impact of errors generated due to workload levels on the information quality?"

To address the above issues, we are exploring the integration of the traditional task network model and IPM. We believe that this integration is a step towards a comprehensive C3I battlefield research environment that will allow us to explore consequences of various operational scenarios, different configurations of technology, assignments of functions, and roles in the MI systems.

2 INTELLIGENCE PRODUCTION MODEL

In modeling human performance, deficiencies in intelligence output are assumed to result from errors that occur in the production process and data operated on during the process (Burnstein 1991, Warner and Burnstein 1996). Thus, a decision was made to focus on modeling (and subsequently simulation) of the effects of errors on human performance in the production of predictive intelligence. Errors are defined as behaviors that degrade the level of performance. They result from enabling conditions and are controlled by information variables, triggering variables, and state variables.

The intelligence production input-process-output and error models (called here the performance model) themselves cannot provide an insight into the value of information produced by an MI system. A research effort was therefore undertaken to establish what constitutes information value, how to represent it and how to process it in a computational sense. A knowledge representation structure, called Intelligence Conceptual Map (ICM), was developed to capture information entities and clusters (as well as relations among them) involved in the MI production. This map establishes a hierarchy of epistemological levels that span a spectrum from data, through primitive information sets and information, to knowledge. The highest level, ie. the knowledge level entities are concerned with prediction information such as for example future Enemy Courses of Action (ENCOA). A sample MI conceptual map is shown in Figure 1.

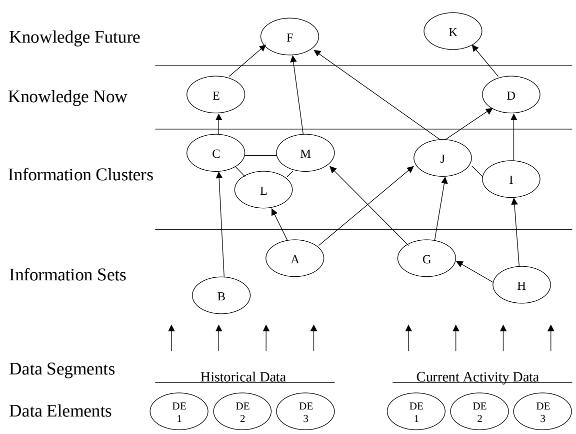

Figure 1 Sample Intelligence Conceptual Map

We had decided to employ the map to address information quality. The ICM and the performance model were combined into the overall IPM. The following basic assumptions and procedures were defined in order to establish how to judge information quality: First, relevance, completeness, and specificity were designated as attributes of information at an ICM node. They were considered in five aspects, namely behavioral, spatial, temporal, structural, and quantitative. The baseline values of the attributes were established as a result of interpreting the commander's Priority Information Requirements (PIR). These values, called I_r (information required), are associated with the ICM nodes. Next, data paths in the form of AND/OR graphs are extracted from the ICM graph. These data paths are generated by adding to a node all its children which contribute to the information in that node. The AND relation indicates that all the children must contribute. The OR relation signifies that not all of the children must be taken into account when deriving the parent node's attributes. The data paths are used to calculate the attribute values based on the underlying database. This information is termed information contributed, I_c. Its calculation is based on a set of rules for propagating the database derived values up and across the data paths. When the information contributed is at the same or higher level as the information required, we assume that the PIR has been met and the quality of information is at an appropriate level. Otherwise, the information contributed is deficient.

The above is the first, initial phase of the model execution. In the second phase, the ICM node values are converted to an error set for the Information Variables (IVs) in the performance model. The performance model (also called the IPM Engine) is run and the effects of errors are propagated back to the conceptual map. The impacted nodes' values are recomputed. Subsequently, new values of I_c are obtained. The final judgment about information quality can now be made. Additional introspection into why a deficiency has occurred and what variables have contributed to it is also be available by backtracking the links in the conceptual map. Figure 2 depicts the relationships among the core elements of the IPM and the corresponding data flows.

The development of the IPM reflects conventional modeling theory based concepts. The underlying real system is the MI production process. The "input-process-output" relation establishes how intelligence results as an output from the production process given input data. In other words, at the highest level of observation, the input is "raw" intelligence data, the observable output is the intelligence produced by the system. As mentioned before, IPM facilitates evaluation of intelligence effectiveness based on the error framework. This framework does not use a mathematical formalism to specify a set of instructions for generating data. Instead, rules for occasioning errors are built into the model description. The dynamics of this model is not a function of time. Rather, it is implicit in the processing steps which are associated with each functional node and transitions from one node to another.

The ICM is a knowledge representation structure that captures information entities and clusters (and relations

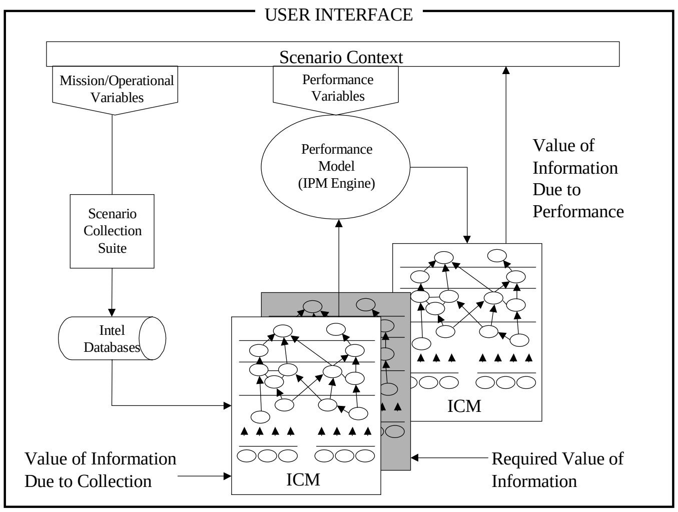

Figure 2 IPM Elements and Data Flow

among them) involved in the MI production. In the IPM, the ICM module is augmented with a set of rules that operationalize the notions expressed in the declarative ICM graph. As stated earlier, relevance, completeness, and specificity were designated as attributes of information at an ICM node.

Clearly, completeness, and specificity (relevance is considered invariant) are the output variables of interest that enable us to make judgments regarding quality. Parameters must be provided to derive the values of these variables and adequate input variables. The inputs include scenario, unit information, assets, etc. The parameters are operational parameters (OP), model sensitivity, OP precedence, and other constraints (for a detailed specification of all the variables and parameters of the model, refer to (McLean and Knapp 1999)).

The IPM development process involved a collaboration of subject matter experts (SMEs), behavioral and computer scientists. It was unique in that a) there was no repository of previous modeling knowledge which we could have used as the basis for this project, b) the underlying domain is not well structured, the elements of the real system cannot be modeled using a homogeneous formal system specification, c) the developed model combines qualitative and quantitative approaches for information processing, and d) the model dynamics is expressed implicitly through the simulation processing steps rather than an explicit notion of time.

3 COMMAND AND CONTROL (C2) HUMAN PERFORMANCE MODELING

The Army C2 community is concerned with how new information technology and organizational changes projected for tomorrow's battlefield will impact soldier tasks and workload. To address this concern, an initiative to model soldier performance under current and future operational conditions was undertaken. In this way, the impact of performance differences can be quantitatively assessed so that equipment and doctrine design can be influenced in a timely and effective manner.

A multi-year research and development effort was undertaken to assist the Army in evaluating tradeoffs between varying configurations of soldiers and equipment in the C2 environment. The work consisted of a series of phases (eg. task-network design, performance data collection, model programming, etc.) which resulted in a number of computer-based C2 models. Models were developed to represent maneuver unit C2, starting with a baseline model to reflect the battalion command post of today, and then several alternatives, each designed to portray selected variations in unit personnel, equipment, and organizational dynamics. Thus, the models could be rerun after changes to the original soldier-equipment settings were made, to allow comparative "what if" analyses. Therefore, it was important for the model to be sensitive to any changes in the performance of the C2 tasks and functions modeled.

Many resources were used to determine the task and work flows conducted in a TOC during a long movement

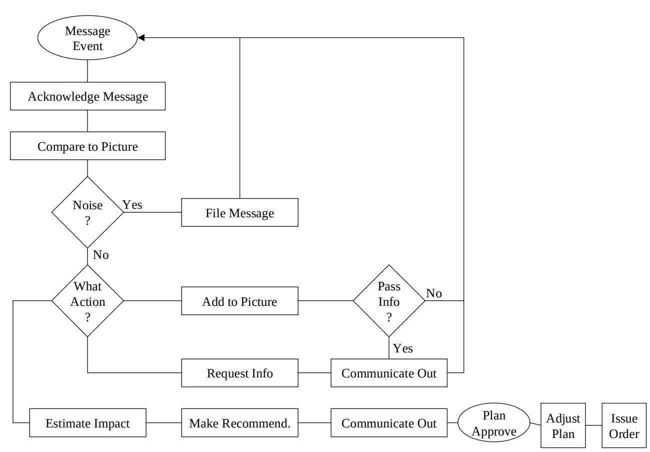

Figure 3 Workflow Diagram for C2 Staff Sections

mission. These included subject matter experts (SMEs), training manuals, doctrine, Standard Operating Procedures (SOPs) and many other sources. The information gathered from all these sources was consolidated into a basic work flow diagram shown in Figure 3. This task and workflow is representative of what is accomplished in each of the staff sections or Battlefield Operating System (BOS) and also individually by each operator. It does not include subtasks associated with passing information within each section because flow from person to person varies according to how many and what rank of soldiers are present in each section.

A message or piece of information comes into the TOC. It is acknowledged, compared to what is currently known, and a decision is made what additional action is necessary. If the message is a request for information as shown by the "Request Information" box, the result goes directly to "Communicate Out." The information may be needed to update the battlefield picture prior to passing to someone else. If the message contains relevant information the operator must determine the impact and make another decision. If an adjustment to the current plan is required, the operator will call together other staff members into a "staff huddle" (Adjust Plan). They will go through a process that includes problem definition, data gathering, finding options, comparing alternatives, making recommendations and communicating out their decisions.

The battalion TOC comprises several sections. Generally, in each section, the messages arrive by various radio nets and are written down on formatted message pads and logged into a log book by a designated Radio-Telephone Operator (RTO). The RTO then passes the message to the next senior person within his section by either distributing the message to the next senior person's in-box or interrupting the person and verbalizing the message. The next senior person may also be monitoring the radio to filter incoming messages; he distributes messages to other sections as deemed appropriate, scans map and status boards for changes and makes the changes based on message traffic. Map updates or changes are made using "stickies" (similar to Post-it notes) posted on map overlays; status board changes are made by erasing data and rewriting it. If a third (more senior) person is in a section, this individual monitors radios, scans map and status boards, decision support templates and other action lists such as the Commanders Critical Information Requirements (CCIR).

In addition, this person estimates the impact of the changes, makes decisions, may initiate staff huddles, and directs actions in the form of verbal orders or outgoing radio messages. In the two-person section, the senior person estimates the impact of the changes, makes decisions, may initiate staff huddles, and directs actions in the form of outgoing information. A typical section network and flow is shown in Figure 4.

A task flow was modeled using MicroSaint™ (Micro Design and Analysis, 1998) simulation package. A scenario of actual messages coming into the TOC during a 24-hour long movement mission drives this model. By recording the task, task times, and skill and ability of the soldiers during this mission while stationary and moving, we can measure the impact on the operator of performing C2 functions "on-the-move."

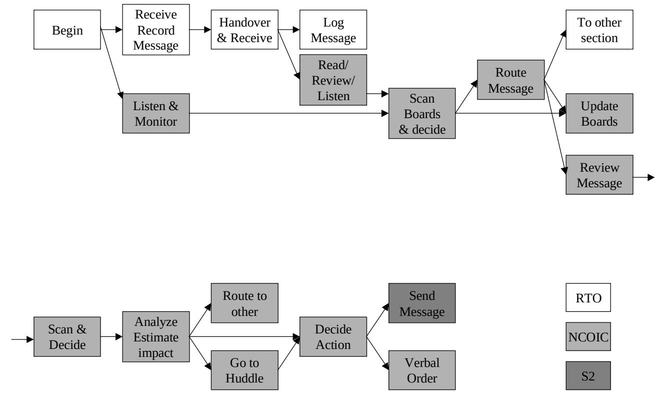

Figure 4 Typical Sections Network and Flows

More specifically, as tasks are triggered and the operators perform them, the skill demand for each operator is recorded. The model keeps track of when the operator begins and ends each task, when and why he is interrupted, what messages are in queues and how long each task takes. Each model run produces a list of output files that are processed to determine the impact of "on-the-move" operations.

The outputs of the model are a set of data files. MicroSaint™ allows specific snapshots of data and variables to be set in advance so that the data files reflect what the user would like recorded. These files list each task the operator executed, when he started, when he stopped, what message he was working on, his cumulative utilization, and his change in skill demand. In addition, each time an operator finished working on a message whether it was a "natural" end or a dropped message was recorded as well.

During the run, at preset time intervals, operator utilization, skill demand, number of tasks performed, running totals of interruptions, suspensions, and dropped messages were all recorded. All operator interruptions were captures as well as what message caused the interruption. At the end of the simulation, the total processing time and total time elapsed or the time spent in the TOC for each message. the total skill demand for each operator by skill category and the time each operator spent using each of the skill categories were documented as well.

These data provided a detailed analysis of what each of command and control operators were doing during the course of the 24-hour scenario. Skill demand changes over time, types and durations of tasks being executed, the number of messages not attended and the reasons, and which tasks that were completed in a timely manner can all be determined. Analysis of the data also allows an assessment of the effectiveness of the C2 system by determining which messages were not processed in a timely manner, and then relating these data to subsequent battle outcomes. It is no overstatement to say that these models are very sensitive to even minor changes in C2 operator task variables as reflected in very different performance in a stationary versus in a moving vehicle.

The Intelligence Production Model and task network models are the basis for constructing an integrated modeling environment that will enable the users to assess intelligence production performance from the perspectives of work flow, information quality, effectiveness, and efficiency. We call this environment C3I meta-model.

4 TOWARDS C3I META-MODEL

The IPM and the task network models, when integrated, will broaden the range of possible applications and will allow us to answer questions about any C3I system, including the consequences of different configurations of soldiers, technology, and assignment of functions and roles. The roles and interactions of the combined models are shown in Figure 5.

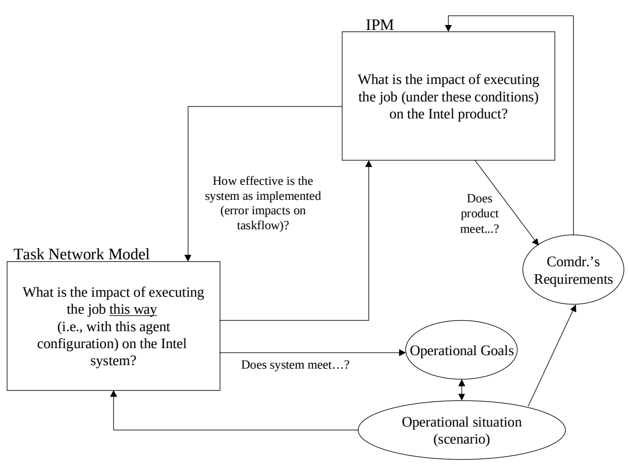

Figure 5 Integration of IPM and Task Network Models

In order to set up a case study, users would create a configuration and an event scenario. A configuration describes personnel, systems, and assets as well as function and roles of the soldiers. A scenario is a set of events (message traffic) that occur over time during the case study. Once a case study is set up, the following questions may be addressed through the meta model.

IPM-related objectives:

Given the scenario, operational goals and commander's requirements: "what is the impact of the traditional (S2) section performance on information product in terms of that product's ability to meet commander's information requirements and operational goals?" Instances of questions include: "what is the impact of providing the S2 section with directly taskable UAV support?", "what is the impact on information quality and system effectiveness of dispersing S2 section functions into multiple vehicles with other distributed section functions?."

Task Network-related objectives:

Given the scenario, operational goals and commander's requirements: "what is the impact of the allocation of agents (people, technology and groupings of both) in a particular assignment of tasks and roles on the S2 section's system performance in terms of the system's ability to meet commander's requirements and operational goals?" (An example of a specific question is "what is the impact on throughput of eliminating the RTO-2 staff position?")

Combined IPM – Task Network Model objectives:

Given the scenario, operational goals and commander's requirements: "Is the allocation of agents and assignment of tasks and roles as implemented effective in terms of producing and information product that meets commander's requirements and operational goals?" or "can the S2 functions required to produce quality intelligence that meets the commander's requirements be carried out by a given allocation of agents and assignment of roles and tasks?"

An example of an instance includes the following question: "given the current S2 configuration, where are the bottlenecks? Do the bottlenecks (as indicated by task dropped, workload values, etc.) affect how well the system performs? That is, even though tasks are being dropped, does the commander obtain what he or she needs, or the bottlenecks increase errors and lead to significantly degraded information quality?"

The capture and translation of the above objectives into a form applicable to the meta-model will be accomplished through the notion of experimental frame (Zeigler 1990), ie. the specification of circumstances under which a model (or the real system) is to be observed and experimented with.

The experimental frame definition reflects the objectives of modeling by subjecting the model to input stimuli, observing reactions of the model by collecting output data, and controlling the experimentation by placing relevant constraints on values of the designated model variables. The data collected from such experiments serves as a means of evaluating the effects of intended interventions. In essence, we define what constitutes model inputs, outputs, and parameters and thus we can explore various "what-if" scenarios by selecting different combinations of such variables and parameters. The gradual process for developing a frame involves the following steps: a) specify objectives, b) specify questions, c) specify variables, and d) specify measurements.

This is a mental process for defining what we need to measure in he model, through what variables, in order to answer the questions which stem from the purpose for which the modeling exercise has been undertaken. This process leads to a specific designation of output variables that we must observe and inputs that are necessary to generate such outputs in a given model. Notice that we make a clear distinction between what drives the model, what is observed as its output, and the model itself. If we follow such a clear distinction, a model can be instrumented with different experimental frames, each corresponding to a particular objective and an "what-if" scenario.

The experimental frame concept is the basis for providing a high level interface between the two models that is transparent to the users. The initial design for such an interface has been developed and prototyped by ARL Field Elements, Ft. Huachuca.

We have also developed an initial approach to the conjoint execution of the two models. The interaction scheme between the IPM and task network models can be summarized as follows:

a) run task network model until workload, tasks in queue and number of tasks dropped reach a threshold
b) run IPM to produce a snapshot of errors produced at that task network state
c) translate IPM state variables into adjustments to workload and information state flow
d) repeat until end of experiment observation interval.

CONCLUSION

The IPM and task network models afford a spectrum of various evaluation scenarios (a scenario is a classical example of an experimental frame, ie. a setting of specific input variables and model parameters to obtain outputs that reflect the objective of simulation) and thus allows us to execute a variety of "what-if" type of model studies. The models are modular and extensible. While an application to a different domain would require an extensive replacement of the underlying data structures and rule sets, the C3I meta model can be used as a general modeling framework to assess quality in human-intensive information processing activities.

ACKNOWLEDGEMENTS

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