An Analysis of Space Shuttle Countdown Activities: Preliminaries to a Computational Model of the NASA Test Director.

Bonnie E. John[1] Roger W.Remington[2] David M. Steier[3]

31 May 1991
CMU-CS-91-138 2

School of Computer Science
Carnegie Mellon University
Pittsburgh, PA 15213-3890

Abstract

Before we hear the familiar phrase "All systems are go" just prior to the launch of a space shuttle, thousands of operations and tests have been performed to ensure that all shuttle and support subsystems are operational and ready for launch. These steps, which range from activating the orbiter's flight computers to removing the launch pad from the itinerary of the NASA tour buses, are carried out by launch team members at various locations and with highly specialized fields of expertise. The responsibility for coordinating these diverse activities rests with the NASA Test Director (NTD) at Kennedy Space Center. We are studying the behavior of the NTD with the goal of building a detailed computational model of that behavior; this paper describes the results of our analysis to date. We describe the NTD's performance in detail, as a team member who must coordinate a complex task through efficient audio communication, as well as an individual taking notes and consulting manuals. A model of the routine cognitive skills employed by the NTD to follow the launch countdown procedure manual has been implemented using the Soar cognitive architecture. The paper concludes with several examples of how such a model could aid in evaluating proposed computer support systems.

This research was supported by the NASA, Grant No. NAG 2-634. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of NASA or the U. S. Government.

---

[1] School of Computer Science and Department of Psychology, Carnegie Mellon University
[2] NASA-Ames Research Center
[3] Engineering Design Research Center, Carnegie Mellon University

Keywords: cognitive models, human-computer interaction, Soar, discourse analysis

1. INTRODUCTION

We are studying the job of the NASA Test Director (NTD) at the Launch Control Center (LCC) at Kennedy Space Center (KSC) with two objectives. The first is to build a computer simulation model of the perceptual, cognitive, and motor processes performed by the NTD in the course of preparing for launch; the second is to use that model to evaluate and indicate changes in the NTD job, training, or computer support aids, that would facilitate or improve performance during launch preparation.

The NTD is one member of a team of hundreds of engineers and technicians, the *launch team*, that performs the many tests and verification procedures leading up to the launch of a space shuttle. The NTD, in particular, is responsible for coordinating and tracking the progress of those procedures. In addition, the NTD is responsible for managing any emergency actions necessary during a launch countdown. This job, especially late in the countdown or under emergency conditions, is extremely demanding. In the course of a typical countdown, the NTD schedules thousands of crucial tests and verification procedures for all shuttle systems, processes hundreds of requests from other team members for the limited resources of time, space, and equipment, and monitors tens of communications channels simultaneously.

Shuttle missions are more frequent than previous manned space programs, and it is the objective of the shuttle program to increase frequency even further. An increase in launch frequency raises concerns about greater efficiency and decreased NTD training time. One path to greater efficiency involves a major hardware and software upgrade now in progress that will provide the opportunity for substantial improvements in display and control technology. Given this opportunity to develop new computer support systems, NASA seeks to understand the knowledge and processing demands of the NTD's job during launch. Such an understanding may allow the evaluation of computer support systems and their impact on both expert performance and training. Our study of the job of the NTD is a first step toward understanding, evaluating, and modifying those demands.

Our work begins with field observations of the NTD's job and analyses of the behavior observed. We then proceed to model mechanisms sufficient to produce that behavior within the Soar cognitive architecture (Newell, 1990). Our goal is to produce a full-fledged psychological model that produces the same behavior as an expert NTD, with an indication of how much time that behavior will take and what knowledge structure and situational information is necessary, within human perceptual, motor, and information processing capabilities. We expect that this research will also contribute more generally to the development of a computational framework for analyzing other complex tasks.

We expect that a mechanistic, computer-simulated psychological model of NTD performance will provide information relevant to the design of the NTD's job and training. The model itself will provide a testbed for design changes. For instance, if a new visual display of status information is suggested, the features of this display could be given to the model with different task scenarios and the model would provide a prediction of the changes in performance due to that display. In addition, the model will provide a trace of the internal processes involved in performance. This trace can give insight into what changes might best benefit the NTD. For example, the model may indicate that at a particular point in the job, much effort is used switching attention between several tasks not because they need to be monitored, but because constant refreshing of the model's memory is required to be ready in case a task turns critical. This might suggest that an external display of the critical information could be introduced to relieve this memory and attention burden. In terms of training, the model will provide information about the possible knowledge representation used by NTDs. Analysis of the use of these structures may suggest a change in training that would produce more efficient representations.

2. THE JOB OF THE NASA TEST DIRECTOR

The launch of a space shuttle is the culmination of a sequence of tests and construction involving several hundred people over the course of several months. The solid rocket booster, main engine, payload, and the orbiter itself are tested and outfitted separately by teams of specialists, then mated and moved as a unit onto the launch pad. Testing and preparation continue with the vehicle on the launch pad until all critical systems, including those associated with the launch pad and the LCC itself, are verified to be functioning within normal limits. From the time a shuttle orbiter returns from its mission until it is launched again over 100,000 staff-hours of work will have been done involving more then 2000 people in performing thousands of separate tests.

The NTD is that member of the launch team responsible for coordinating all phases of shuttle preparation; he is the focal point for all engineering and safety tests conducted during countdown. The NTD must manage and implement the schedule that guides shuttle progress during all phases of preparation. During the final phases of countdown, the NTD must make critical, time-constrained decisions concerning launch status, while fielding a constant stream of auditory messages from other team members that update that status. It is important to emphasize that although technical problems are reported to the NTD, the NTD is not a technical troubleshooter. Rather, the NTD *coordinates* launch activities, including directing communication between technical troubleshooters, that is, the NTD must know whom to ask if there is trouble. Ultimately, the NTD must give the Launch Director the final assurance that the shuttle is ready to launch.

The NTD is physically located in the Firing Room of the LCC. Figure 1 shows some of the stations and their approximate layout in the Firing Room. During countdown the Firing Room is staffed by a team of over 200 engineers and technicians at stations concerned with specific launch subsystems, including fuel, engines, software, electrical systems, and instrumentation. The NTD position is in a row elevated slightly above the subsystem workstations. During launch, eight or more people may occupy the NTD row. These people include the Prime NTD and the Assistant NTD, who shares some tasks with the Prime NTD. (Our observations indicate that the Prime NTD remains at the NTD station, performs all the communication, and much of the note-taking, during the time period of interest, T-20 min to launch. Our use of the term "NTD" refers to the Prime NTD.) The NTD can see and communicate directly with the people on his row, and by standing up can see over his equipment to the some, but not all, of the other workstation operators. Above and behind the NTD is the Launch Director who is responsible for the final OK for launch.

The primary form of communication between the NTD and other members of the launch team is over a two-way radio net, the Operational Intercommunications System (OIS). The NTD has one OIS channel assigned to him, but a dozen communications channels appear on his console. In addition to continually monitoring his own channel, the NTD usually monitors several of the other channels simultaneously at reduced volume, all mixed binaurally. Throughout most of the countdown, the NTD may also initiate or receive calls on a private telephone line or make announcements on a public address system. In the last 20 minutes of the countdown, all communications between members of the launch team switch to a single OIS channel, Channel 212.

The primary source of visual information for the NTD is the volumes of manuals that contain the steps necessary to launch the shuttle, collectively known as the Operations and Maintenance Instructions (OMI). The OMI has over 3000 pages, including normal, abort

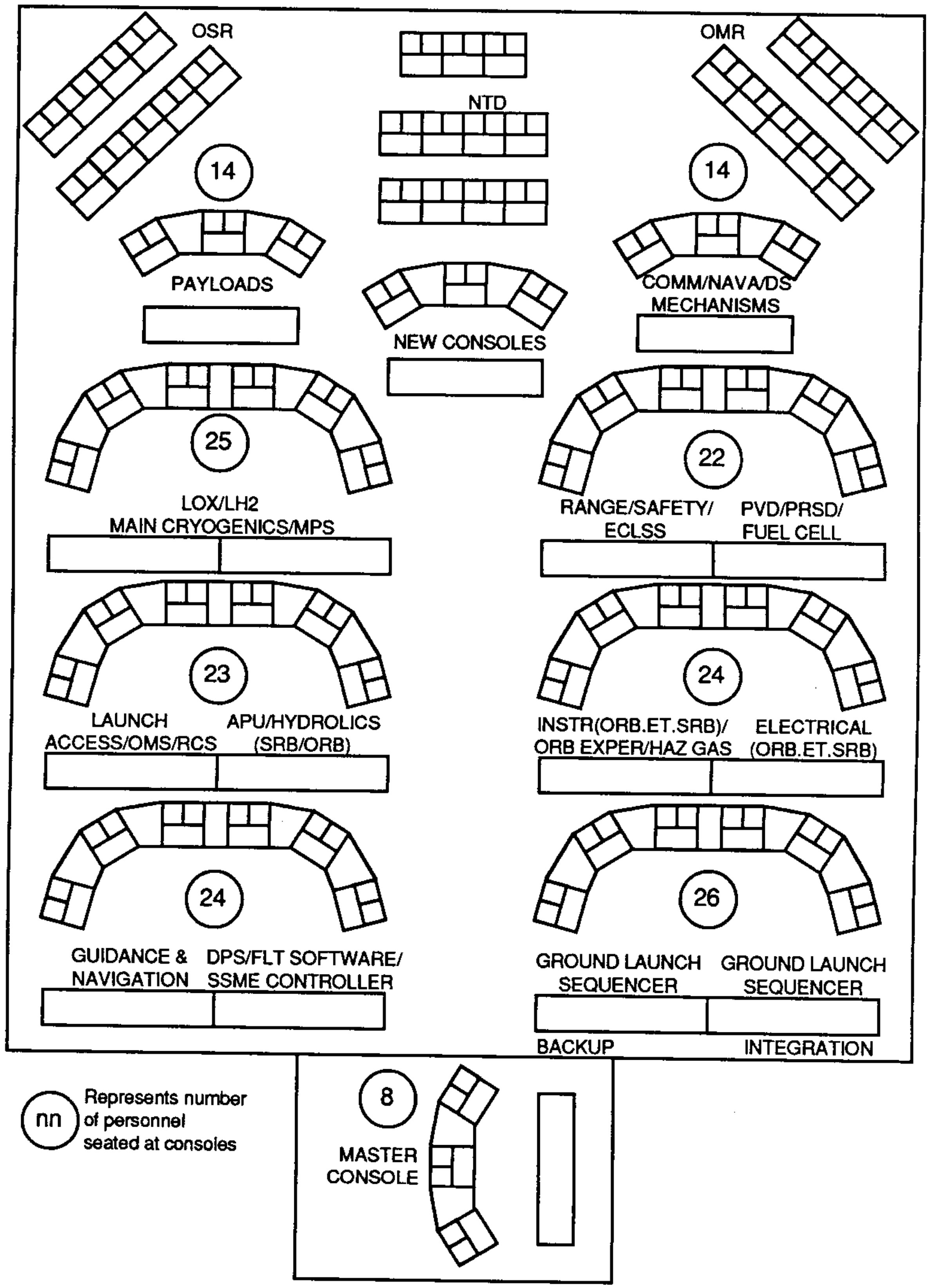


Figure 1. The layout of the Firing Room

(or *scrub*), and emergency procedures divided into about 50 sequences. Each sequence contains a number of individual steps of varying duration and complexity to be performed during countdown. For example, the countdown from T minus 11 hours to T minus 6 hours, the pad closeout phase which the NTDs regard as their busiest time, is covered by the 622 steps of Sequence 15, while the time from T minus 6 hours to T-0 falls under the 1132 steps of Sequence 16. Each entry in the OMI (example page in Figure 2) lists a test or procedure that must be performed to verify a subsystem (DESCRIPTION column), the approximate time at which this step should be completed (TIME column), and the communications protocol that must be followed to complete the step (CMD and RESP columns). The steps are listed sequentially, and given a unique step number (the SEQ column), but in fact many procedures are done in parallel. Constraints on the order of procedure execution are sometimes specified. Not all the steps in the OMI will be performed during any one launch; while some are common to all launches, others occur only in the event of an abort or recycle. Some steps depend on factors such as the duration of the flight, the weather, and the type of payload. Other documents consulted by the NTD are detailed bar chart schedules and a listing of acceptable ranges for thousands of parameters of shuttle systems (the Launch Commit Criteria).

The NTD works from an integrated OMI (which we will call, simply, *the OMI*). Each subsystem manager has a separate subsystem OMI that gives detailed procedures for carrying out the tests specified in the OMI. Unless the procedure specified in the subsystem manual is dependent on the completion of a procedure in another subsystem, or is dependent on some set of initial conditions, subsystem managers will initiate tests without clearance from the NTD. The OMI explicitly specifies when such clearance is needed.

The OMI has evolved from the collective experience of launch teams over the years of NASA's space exploration. In the days of the Mercury project, launch teams developed a list of procedures in order to avoid omissions and to insure that the launch sequence was carried out in the correct order. To help avoid these problems in subsequent launches, they prepared a "guide to launch", listing the major tests and their sequence. Around the time of the first shuttle launch (circa 1980) the initial boilerplate for the current OMI was developed, along with a manual, *The Technical Operating Procedures (TOPS) Preparation Handbook*, that delineated rules and procedures for constructing and modifying the OMI.

Changes to the OMI can be proposed by any member of the launch team when he or she discovers an error or thinks of a way to improve performance. The formal process for proposing and processing changes is described in the *TOPS Preparation Handbook*. Each proposal is discussed by an appropriate subset of the launch team and a written *deviation* is prepared. Every deviation is documented; nothing changes, nor is any part of any task begun, until it is written down in the appropriate document according to procedures set forth in the *TOPS Preparation Handbook*. Some changes require approval at the NTD level; others require higher levels of approval. In any case, no change is the result of a single person's judgment, but involves the appropriate team members. As would be expected in such an evolutionary process, many more deviations were processed in the early years of shuttle launches than are now processed. This revision process, involving the team in proposal and discussion phases, and building on previous launches over a period of years, results in an OMI that is highly trusted and adhered to, but is viewed as a document that can be changed when the need arises.

The current set of visual inputs normally used by the NTD does not include any integrated computer display on which the progress of the launch can be viewed. Several small CRT screens appear at the NTD's console but are used to display closed circuit television pictures of the launch pad and related facilities, rather than the output of any computer support tools. There are in fact, many computer consoles in the firing room, but it is the

VOLUME 2 OF 5
DATE: 01-29-90

OMI NO. - S0007VL2
REV. - AJ

OPERATION INSTRUCTIONS

SEQ	TIME	CMD	RESP	DESCRIPTION	VERIF.
16-0905	"-20M00S (HOLDING)	OTC	ALL	AFTER TRANSITION TO OPS 101; DISCONTINUE ALL LDB PMU READS FOR REMAINDER OF COUNTDOWN. RESUME COUNT NOTE CGLS WILL MONITOR LPS AND GPC COUNTDOWN TIME. IF A DELTA OF GREATER THAN 2 SEC DEVELOPS, CGLS WILL NOTIFY NTD AND CDPS.	
16-0906	"-20M00S (HOLDING)	CGLS 212		CDC WILL START ON MY MARK 3-2-1 MARK	
16-0907		NTD PA		T-20 MINUTES AND COUNTING ________________ GMT FUEL CELL PURGE NOTE CFCP TO PERFORM FUEL CELL PURGE PER CDC.	
16-0908	"-20M00S COUNTING		CFCP	PERFORM FUEL CELL PURGE PER SEQ 47 (S00007VL4) ON OIS CH 153. REPORT COMPLETION. OMRS S00FJ0.050	*BCS
16-0909			JRPS	START GNC STRIP CHART RECORDERS (OMI S9002VL16).	

Figure 2. A page from the OMI

responsibility of the personnel at the subsystem and integration stations where these consoles are located to interpret the displays, and relay any significant developments to management over the OIS communication network.

When a subsystem has completed the tests required to fulfill an OMI procedure, the subsystem manager calls the NTD on an OIS channel and informs him of the step completion. In practice, such completions are often grouped, so that the NTD receives a sequence of step completions from a subsystem manager. Upon receiving a step completion, the NTD marks the step as completed in his copy of the OMI. Again, in practice, the NTD may acknowledge the completion, write it on a piece of note paper, and defer the sign-off in the OMI until later. If steps are skipped or not yet completed, the NTD may insert a Post-It ™ in the OMI to mark the uncompleted page. In addition, the NTD makes log entries that serve as a record of activity. Log book notations are especially important when anomalies occur.

If a system fails, tests fall outside their normal ranges, or any of a number of anomaly conditions hold, the NTD coordinates the response. A problem may involve a number of subsystems; the NTD may establish a separate communications channel and assign personnel from the appropriate subsystems to communicate technical information over that channel. The NTD is also responsible for predicting the effect of the anomaly on other aspects of the launch. A failure in one subsystem may cause procedures in other subsystems to be rescheduled. The countdown clock can be stopped, and there are fixed *holds* which can be used to accommodate such delays. At other times, as, for example, once the hydrogen and liquid oxygen have been loaded, the clock can be held only a short, fixed, time before the launch must be scrubbed. Dealing with anomalies is a difficult aspect of the NTD's job. The launch is dynamic, and conditions (such as weather) change quickly, so that holds must be carefully planned. Response to an anomaly involves increased planning, increased communications, and critical decision-making.

As previously mentioned, there is little or no computer support used routinely by the NTD to aid in the various tasks. Although the OMI itself is updated often and maintained electronically to facilitate those changes, its on-line version is not accessible to the NTD. Bookkeeping activities, such as marking pages in the OMI or making notes about status, are done by hand. There is no integrated display on which the progress of the launch can be viewed. Rather, this information is primarily kept in the NTD's head. There are few external memory aids that can be easily accessed -- the OMI is the principal source -- and no on-line aids to track the progress of on-going procedures.

The job of the NTD has evolved to fit the methods and facilities available. The possible introduction of new facilities with the major hardware and software upgrade now in progress may suggest changes to these methods. It is our goal that this research will aid in evaluating such changes so that a technical revolution in information capabilities will not undermine the evolution in cooperative work that has produced the current standard of efficiency and safety.

3. DATA COLLECTION AND DESCRIPTIVE ANALYSIS

We spent a week in the LCC at KSC to become familiar enough with the NTD's job to begin analysis. The NTD's office graciously made several sources of information available to us: direct observation of NTDs performing both routine and critical operations, conversations with NTDs when they were not on duty, copies of the OMI and other documentation, audio tapes of actual pre-launch communications, and discussions with a member of the training team who conducts simulations of countdowns from T-20 min to launch or scrub. (Simulations are used to train apprentice NTDs in launch procedures and keep experienced NTDs familiar with rarely used emergency procedures.) At this point in the research, we were not able to observe the portions of the count down when the NTD is busiest (T-11 hours to T-6 hours), nor could we observe a launch.

Based on the observations and conversations, we selected T-20 min to launch as the first segment of the countdown to study. This period is busy enough to be interesting and challenging, as our descriptive analysis will show, and yet structured enough to allow us to begin with a limited model. For example, rather than modeling the NTD as he monitors several communications channels simultaneously, our model can be limited to a single auditory input channel because all launch-critical communications are on channel 212 during this period. Also, this segment is perceived to be more routine, containing fewer deviations from prescribed order of steps, and to be more similar from launch to launch by the NTDs. An additional benefit is that the T-20 min to launch segment of the countdown is the segment that can be simulated in training runs; when our model makes predictions about performance with different computer-support aids, we may be able to test these predictions via simulation.

The NTD's office gave us audio tapes of the NTD's communication channel from three actual launch attempts: two launch attempts on consecutive days that were scrubbed and a third that ended in a successful launch two days later. We transcribed and timestamped the first attempt from T-20 min to scrub at T-31 sec, the second attempt from T-20 to scrub after an extended hold at T-9 min, and the third attempt from T-20 min to launch. Earlier portions of these launch attempts were listened to but not analyzed in detail. In addition, we were given an audio tape of the NTD's channel from a training simulation. At our request, the NTD's office videotaped activity from T-11 hours to T-6 hours. Although this is not the launch phase we will initially model, the NTDs view this time period as their busiest and most critical time. Portions of the video tapes were viewed and the physical interactions with equipment and personnel were noted. In general, the same types of interactions occur here as in the T-20 to launch time period, however the frequency of activities may differ.

Before beginning a quantitative description of aspects of the NTD's performance, it is useful to characterize NTD behavior qualitatively. There is much cyclic, quasi-predictable sequenced behavior. During quiet periods, the NTD is either awaiting status update information, or seeking launch status information. When a subsystem manager calls the NTD to report status information an activity sequence begins that seems to be a local, immediate response to that status information. The NTD acknowledges the message, finds the indicated step in the OMI manual, and updates the manual. This patterned activity may vary in slight detail from one NTD to another, and during periods of high message load, the NTD may write notes indicating which steps have been completed rather than searching the manual at the time the step is given. The occurrence of unexpected events - failure conditions, or adverse weather - disrupts the programmed flow of events. The NTD must then track and amend the progress of the launch concurrently with the progress of the anomalous conditions.

To illustrate the NTD's behavior we created a variant of problem behavior graphs (Newell and Simon, 1972) that capture the nominal flow of events as described in the OMI, and the actual sequence of events, including interruptions. Figure 3 is our analysis of a simulated launch attempt; Figure 4 of an actual launch attempt. The ovals represent phrases spoken in a single *message* by a single individual. The darkest grey ovals are messages *spoken by* the NTD, the lighter grey ovals are *addressed to* the NTD, and the white ovals are messages on channel 212 that *do not directly involve* the NTD. The column labelled "Prescribed Procedure" contains a column of ovals whose contents are the step numbers in the OMI and numbers associated with the messages about those steps. This column is ordered in the

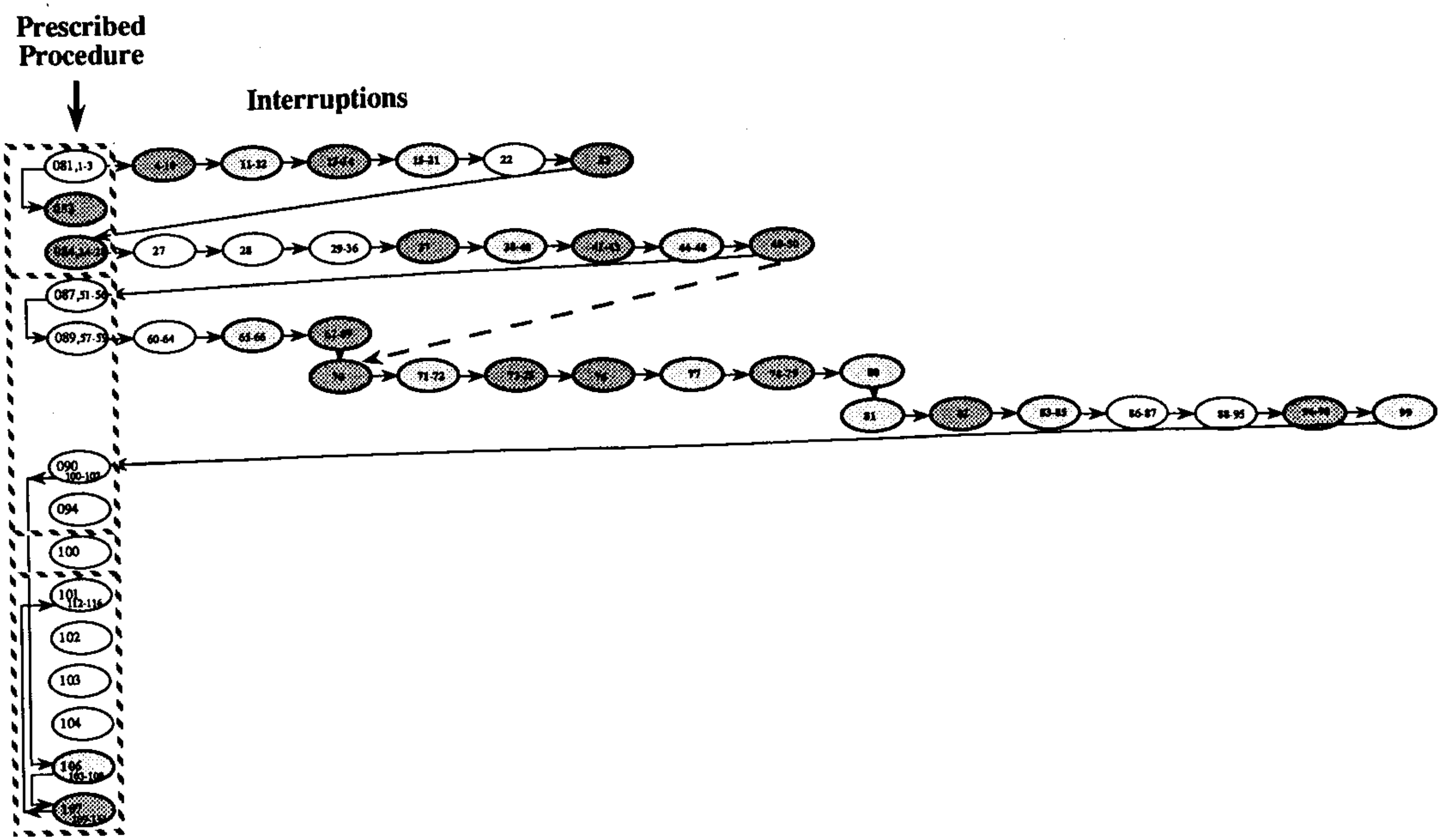


Figure 3. Problem behavior graph of a launch simulation

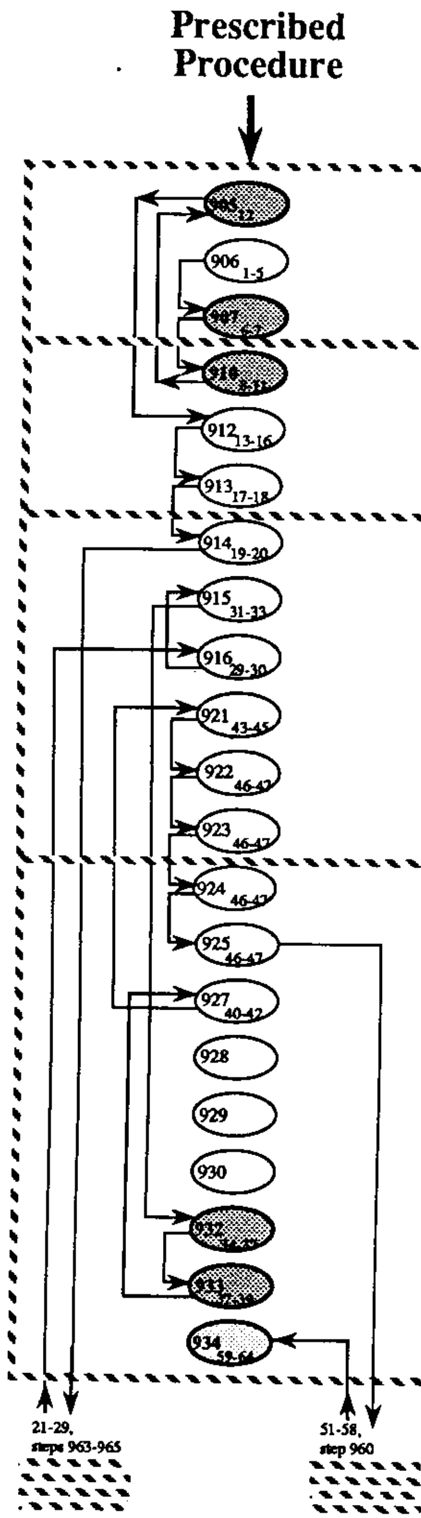


Figure 4. Problem behavior graph for actual countdown

sequence in which the steps occur in the OMI. The arrows to the left of the ovals connect steps in the order in which they occurred in the transcript. For example, the sequence of events starting with step 90 in Figure 4 went fro step 090 to step 106 to step 107 to step 101. The dotted lines surrounding the ovals in the Prescribed Procedure column indicate which procedures are on the same page; crossing a dotted lines means the NTD had to flip a page to see that procedure. To the right of the Prescribed Procedure column are interruptions. These are messages which are not directly related to sequence steps, but refer to anomaly reports or other status information that require a response. The numbers do not correspond to steps in the OMI, but are a running count of the messages dealing with interruptions.

The graph of the simulated launch, Figure 3, shows a relatively regular following of the prescribed procedures, with long interruptions due to anomalies inserted into the simulation. This is to be expected because the purpose of these simulations is to familiarize the NTDs with rarely used emergency procedures. As would be expected, there are fewer interruptions in the actual launch (Figure 4) than in the intentionally difficult simulation. But the procedures are more out of order in the real launch than in the simulation. This means that the NTD must spend substantial time turning pages in the OMI searching for the step to be signed off.

For a more detailed description of the behavior in the launch tapes, we define an *utterance* to be verbally spoken words, strings of words, or sounds (e.g., "uhmmm") bounded by 100 ms or more of silence. We define a *message*, as used above, to be a sequences of utterances by a single speaker to a specific listener or listeners, without interruption by another speaker. We define a *conversation* as a sequence of messages between two or more specific speakers. We then transcribed each utterance, marked it with its speaker, and assigned it to a message and to a communication episode. (Appendix 1 contains about 15 minutes of communications transcribed and marked in this manner.)

The annotated transcriptions allow us to quantitatively describe some aspects of the NTD's job. One important aspect is the communications load. The timed transcriptions permit a description of message traffic density on channel 212, as well as an idea of how much time the NTD must devote to communications. The unit of analysis is the message, or sequence of utterances that comprise one speaker's turn. The total elapsed time for the first launch attempt (25Feb90), measured from T-20 min to the abort at T-31 sec, was 30.2 min. The combined duration of all messages was 11.33 min. Thus, approximately 38% of the time there was message traffic on channel 212. For the 26Feb90 attempt, the tape was analyzed from T-20 min to the beginning of a lengthy, and final hold at T-9 min. The total elapsed time during this period was 14.82 min. Total message duration was 5.08 min, or 34% of the total time. A 23.89 min segment of the 28Feb90 launch contained 6.29 min of message traffic, yielding an estimate of 26%. Because of weather problems, this segment, and other segments from that launch containing long periods of silence as the launch team holds awaiting weather clearance, underestimates the normal percentage of message traffic. These analyses suggest that approximately one third of the time there is message traffic on channel 212.

The NTD is the direct participant in only some of these messages. For instance, for the 25Feb90 launch attempt there were 271 messages of which the NTD participated in 166, or 61%. For the 14 min segment of the 26Feb90 attempt there are 119 messages of which the NTD participated directly in 69, or 58%. For the 24 min segment of the 28Feb90 launch the NTD was involved in 105 of the 160 messages, or about 65%. Overall, approximately one third of the messages originate from the NTD. The NTD is clearly the most active participant on the communication channel, and a substantial fraction of his time is devoted to communications.

The NTD may be assumed to be passively monitoring conversations in which he is not directly involved (see Section 4), but a lower bound on the estimate of time spent on communications can be obtained by computing the time spent by an NTD in communication in which he is directly involved as either the initiator or recipient. Of the 30.2 min elapsed time of the 25Feb90 launch attempt segment, the NTD spent 5.68 min in direct communication, or approximately 19%. For the 14.82 min of the 26Feb90 segment, the NTD spent 3.25 min in direct communication, or about 22%. The NTD was occupied with communications for 5 min of the 23.89 min of the 28Feb90 segment, or about 20%.

The mean time between messages can give an indication of how much contiguous free time is available to perform tasks other than communication. The mean time separating the start of one message from the start of the subsequent message for all members of the launch team in the three launch segments were: 6.7 secs for 25Feb90, 7.5 secs for 26Feb90, and 8.4 secs for 28Feb90. Thus, message rate is roughly 8 messages per minute. For the NTD in particular, message rate is necessarily less. The mean time between message starts in which the NTD is either the sender or receiver is: 10.3 secs for 25Feb90, 12.8 secs for 26Feb90, and 14.0 secs for 28Feb90. The NTD's message rate is roughly 5 messages per minute. The average duration of messages for all team members for the three launch segments are: 2.5 secs for 25Feb90, 2.6 secs for 26Feb90, and 2.4 secs for 28Feb90. Thus, for the NTD, the time between the end of one message and the beginning of the next (inter-message interval) is: 7.8 secs for 25Feb90, 10.2 secs for 26Feb90, and 11.6 secs for 28Feb90. On average then, the NTD has about 10 seconds in which to accomplish other tasks between fielding messages. The distribution of inter-message intervals is positively skewed as a results of a few very long intervals, and for most of the time the NTD has significantly less than 12 secs between messages.

One of the significant activity for the NTD that is done in the inter-message interval is marking steps complete in the OMI. Behavior graphs (Figures 3 & 4) have already shown that steps are not completed in the sequence in which they are presented in the OMI, making it necessary for the NTD to flip pages in the OMI in order to find the relevant procedure. We wanted to get some idea of how extensive this page turning was. Unfortunately, the videotape could not be used for this, since the order of step completions is constrained differently for T-20 min than for earlier portions of countdown, and because page flipping was often obscured in the videotapes.

To estimate the amount of page turning in the OMI manual from the audio tapes, we calculated the distance in procedural steps (step size) from one step completion to the next in the transcription of the audio tapes. To get a rough idea of how this translates in to page turning proportions we computed the proportion of times a step size falls into a bin whose size is the number of steps visible on both pages of an opened manual. It turns out that this bin size is about 6; there are between 6 and 7 steps visible at any one time. Figure 5 plots the approximate proportion of times the NTD had to turn a given number of pages in order to find and mark a step completion that had just been given him. In the 30 minutes of elapsed time in which 176 steps were completed, the NTD had to traverse about 200 pages; eight times he had to flip 10 or more pages to find the step. The NTD's tell us that countdown segment beginning at T-20 min is a relatively well-behaved portion of the launch; other countdown stages have many more large transitions between steps. Indeed, the NTDs all complain about the excessive manipulation of the OMI, and are hoping that the improved hardware and software will relieve them of this particular bookkeeping task.

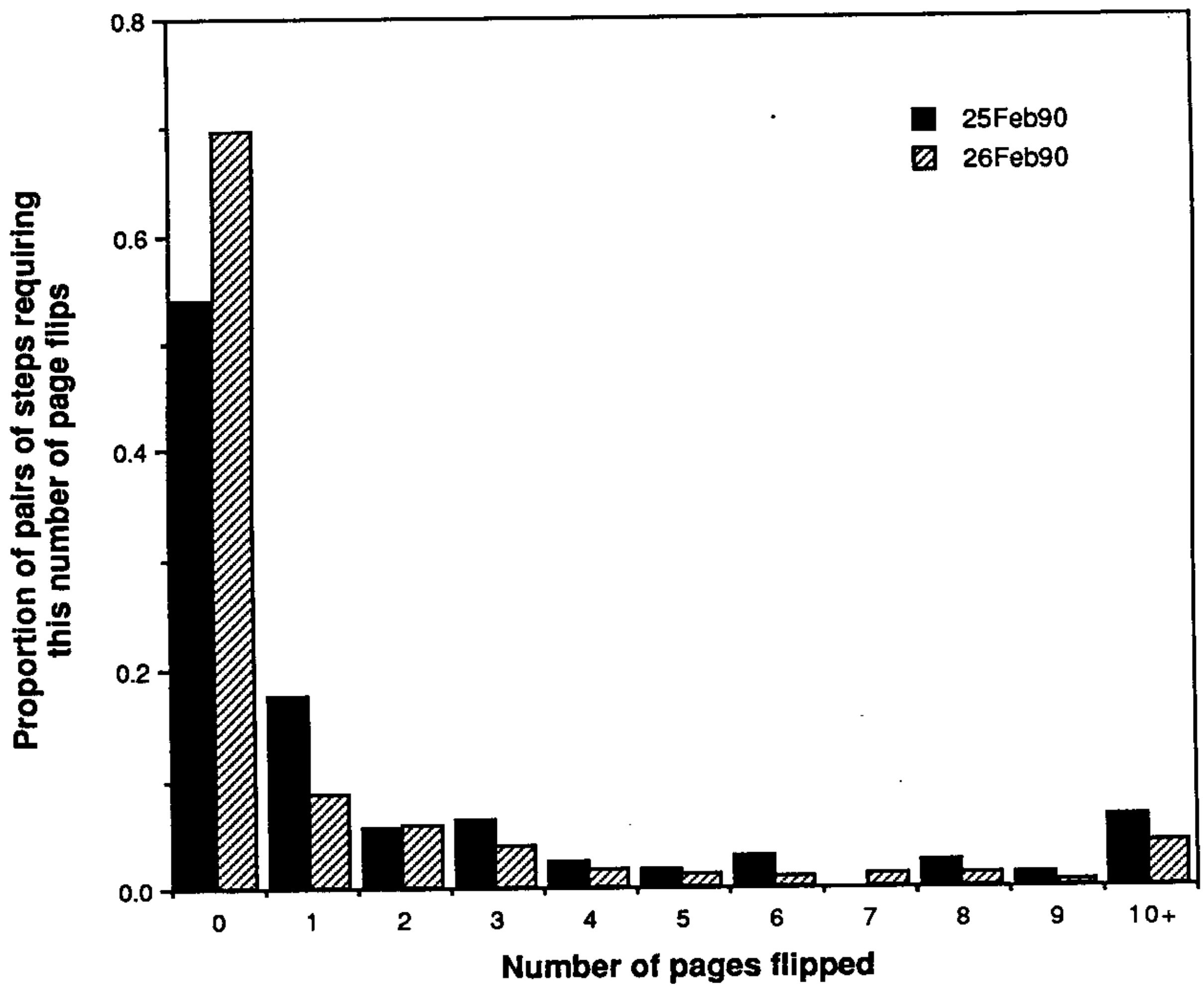


Figure 5. Estimated number of page flips required to locate the current step.

The preceding analyses provide information about the activities of the NTD, how much communication, how much flipping of pages. Viewed in isolation, these activities appear as routine responses to local information. In actuality, each local behavior fulfills part of a larger unit of work. Just as sequences of utterances comprise a message, sequences of messages relate conceptually to larger scale operations. We have begun to identify higher level tasks in two ways. First, we reviewed the transcripts with an expert NTD, who connected together messages that he considered part of the same conceptual task. We then took this annotated transcript and compared it to section headings in the OMI that group steps by function, e.g., FUEL CELL PURGE contains steps 16-0908 and 16-0909. For each utterance, the NTD classified it as belonging to the same larger task unit as the previous utterance, or belonging to a different larger task unit; for each utterance, we made the same judgment using the OMI section headings. In the segment of transcription partitioned by the NTD, there were 91 utterances, and thus 90 opportunities for the NTD's judgment to match the OMI headings. Of these 90 opportunities, the OMI headings agreed with the expert's opinion 77 times (85% agreement).

With this completed we now had a start on understanding what activities the NTDs perform, how much of their time is filled with these activities, and how the NTDs mentally represent their task.

4. THE COMMUNICATIONS OF THE LAUNCH TEAM: A PRELIMINARY DISCOURSE ANALYSIS

In the previous section, we examined the activities of the NTD as an individual in the launch process: the listening, speaking, page-turning, note-taking, etc. involved in doing the NTD's job. A large portion of the NTD's activities are communications with the other members of the launch team. In order to gain insight into the nature of these communications we performed a preliminary discourse analysis of a 15-minute segment of OIS communications (Appendix 1).

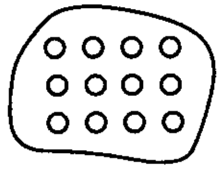
Throughout this analysis, we define an *utterance* to be verbally spoken words, strings of words, or sounds (e.g., "uhmmm") by a single speaker to one or more particular listeners, bounded by 100 ms or more of silence. We define a *message* to be a sequence of one or more utterances by a single speaker to a specific listener or listeners, without interruption by another speaker.

All communication on the OIS after T-20 minutes occurs within a general *discourse situation* (Figure 6a), where every member of the launch team monitors the same communication channel, Channel 212. Within the general discourse situation of universal passive monitoring, there are embedded discourse situations actively involving a subset of launch team members. Discourse situations may be interrupted, maintained as inactive, and returned to, but in practice, the resulting embedding seems to be rarely more than two deep.

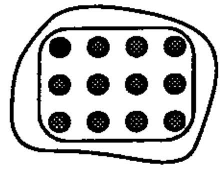
We have identified five types of discourse situations in which some launch team members play active roles. In an *announcement* (Figure 6b), one speaker makes an announcement, comprised of a single message, and all other members are *active listeners*. In a *poll* (Figure 6c), one speaker conveys a request (a message) for information from a subset of the launch team. The members of that subset respond in turn with their own messages and are active listeners to both the request and the responses of the other members of the subset. In a two-party *conversation* (Figure 6d), a speaker and an active listener alternate roles and communicate messages (in a conversation, a message is equivalent to speaker's *turn*). In a two-party *conversation with explicit overhearers* (Figure 6e), several active listeners overhear a two-party conversation with the explicit knowledge of the conversation's participants. Such a conversation is explicitly set up with a *management conversation* (Figure 6f), with the NTD acts as facilitator, relaying a message to appropriate members of the launch team, who then ready themselves for the conversation.

Specific announcements, polls, conversations with or without explicit overhearers, and management conversations, are referred to as *communication episodes* (or simply, *episodes*). Communication episodes are defined by the change from one discourse situation to another, where the discourse situation is defined by both its type, as described above, and by its participants. For example, a sequence of utterances where the NTD finishes a conversation with one person and then, without interruption, begins a conversation with another person, comprises two conversation episodes because of the two different sets of participants.

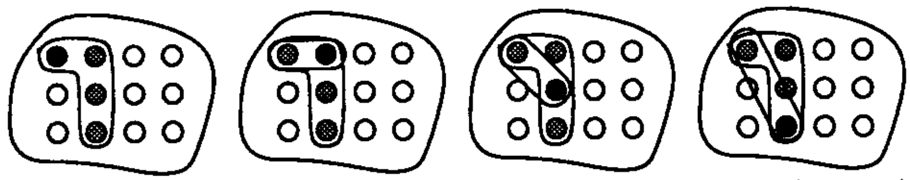
The communications studied included approximately the first fifteen minutes after the countdown started at T-20 minutes on the first launch attempt. This segment of communications contained 164 utterances, which combined to form 125 messages, making



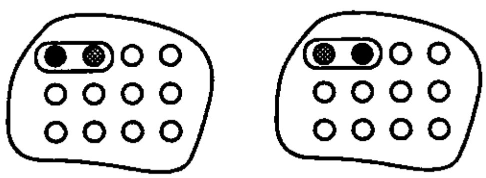
a. General discourse situation, passive monitoring of the OIS.



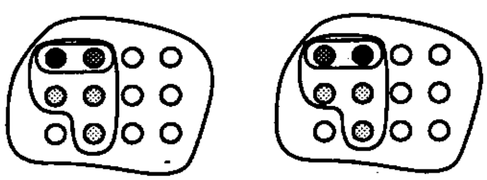
b. Discourse situation for an announcement. One speaker (●) speaks to all others on the net. All others are active listeners (●).



c. Discourse situation for a poll. One speaker requests information from a subset of the team, they respond in turn and are active listeners to the other responses.



d. Discourse situation for a two-party conversation. Speakers alternate turns.



e. Discourse situation for a two-party conversation with explicit overhearers. Speakers alternate turns and overhearers (◎) actively listen.

f. Discourse situation for a management conversation (below). For example, a request for a conversation with explicit overhearers comes to manager (M) from a speaker (S1). M hails S2 telling him to expect the conversation. M hails O1 and O2 telling them to be explicit overhearers. M becomes an explicit overhearer himself, O3, and S1 and S2 converse.

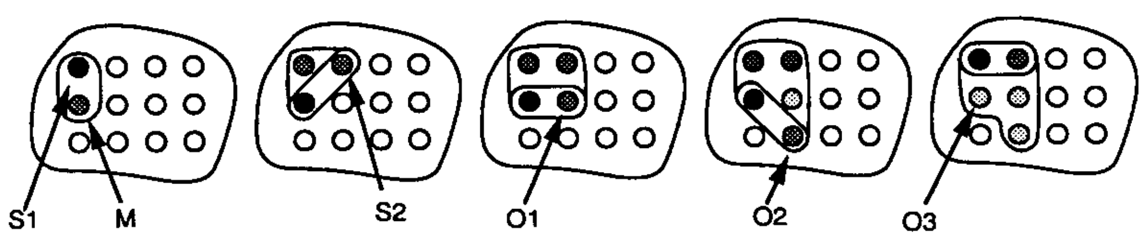


Figure 6. Discourse situations in OIS communication from T-20 minutes to launch. Each circle represents one member of the launch team. Although there are hundreds of members of the launch team in totality, we have chosen to represent only a few for this illustration.

up 42 communication episodes. These communication episodes included 6 announcements, 0 polls, 32 two-party conversations, 3 conversations with explicit overhearers, and 1 management conversation.

A conversation (two-party, with or without overhearers, or management) can be further described by the *information exchanges*[1] contained in it. We have identified seven types of information exchanges evident in the segment of communications studied. The nominal form of a conversation begins with a Summons/Answer information exchange. In the summons half of this exchange, one speaker (S1) states the call-sign of the party with whom he or she would like to converse, then states his or her own call sign, and (optionally) the communication channel on which the conversation should take place. In the answer half of this information exchange, the party summoned (S2) answers by identifying himself or herself, optionally saying the words "Go" or "Go ahead" or identifying S1. After the S/A information exchange, the conversation continues with one or more of the six other types of information exchanges. A conversation of this type has no explicit end; rather, it is bounded by an extended pause or when someone else seizes the channel.

The other six types of information exchange are as follows.

- Request/Promise/Registration - S1 makes a request for information, S2 promises to provide that information at a later time, and S1 registers receiving the promise.
- Request/Compliance/Registration - S1 makes a request for information, S2 immediately complies with that request by providing that information, and S1 registers receiving the information.
- Direction/Registration - S1 directs S2 to do something and S2 registers receiving that direction.
- Assertion/Registration - S1 makes an assertion and S2 registers receiving that assertion.
- Offer/Acceptance/Compliance/Registration - S1 makes an offer to provide information, S2 accepts the offer, S1 provides the information, and S2 registers receiving that information.[2]
- Offer/Refusal/Registration - S1 makes an offer to provide information, S2 refuses the offer, S1 registers receiving that refusal.

These seven types of information exchanges are sufficient to nominally classify over 90% of the information exchanges in the segment of communications studied. Of 85 information exchanges in the 36 conversations studied, there were 39 Summons/Answer, 0 Request/Promise/Registration, 8 Request/Compliance/Registration, 13 Direction/ Registration, 18 Assertion/Registration, 0 Offer/Acceptance/Compliance/Registration, 1 Offer/Refusal/Registration, and 6 unclassifiable information exchanges. Of the 6 unclassifiable information exchanges, 3 were too incomplete to allow classification, i.e., requests that received no response so they could not be classified as either

---

[1] Information exchanges are derived from the adjacency pairs described in Clark, 1985. In fact, the Summons/Answer information exchange is identical to the Summons/Answer adjacency pair. The other information exchanges can be broken down into strings of adjacency pairs. For example, the Request/Promise/Registration information exchange is a Request/Promise adjacency pair where the message that is the promise doubles as the end of that adjacency pair and the beginning of a Promise/Registration adjacency pair. If an Assertion/Registration pair is added to the eight described by Clark, the other five information exchanges are also combinations of adjacency pairs. We have chosen to work at the grain size of information exchanges because it is less cumbersome than strings of adjacency pairs and adequate to describe the conversations found in these data.

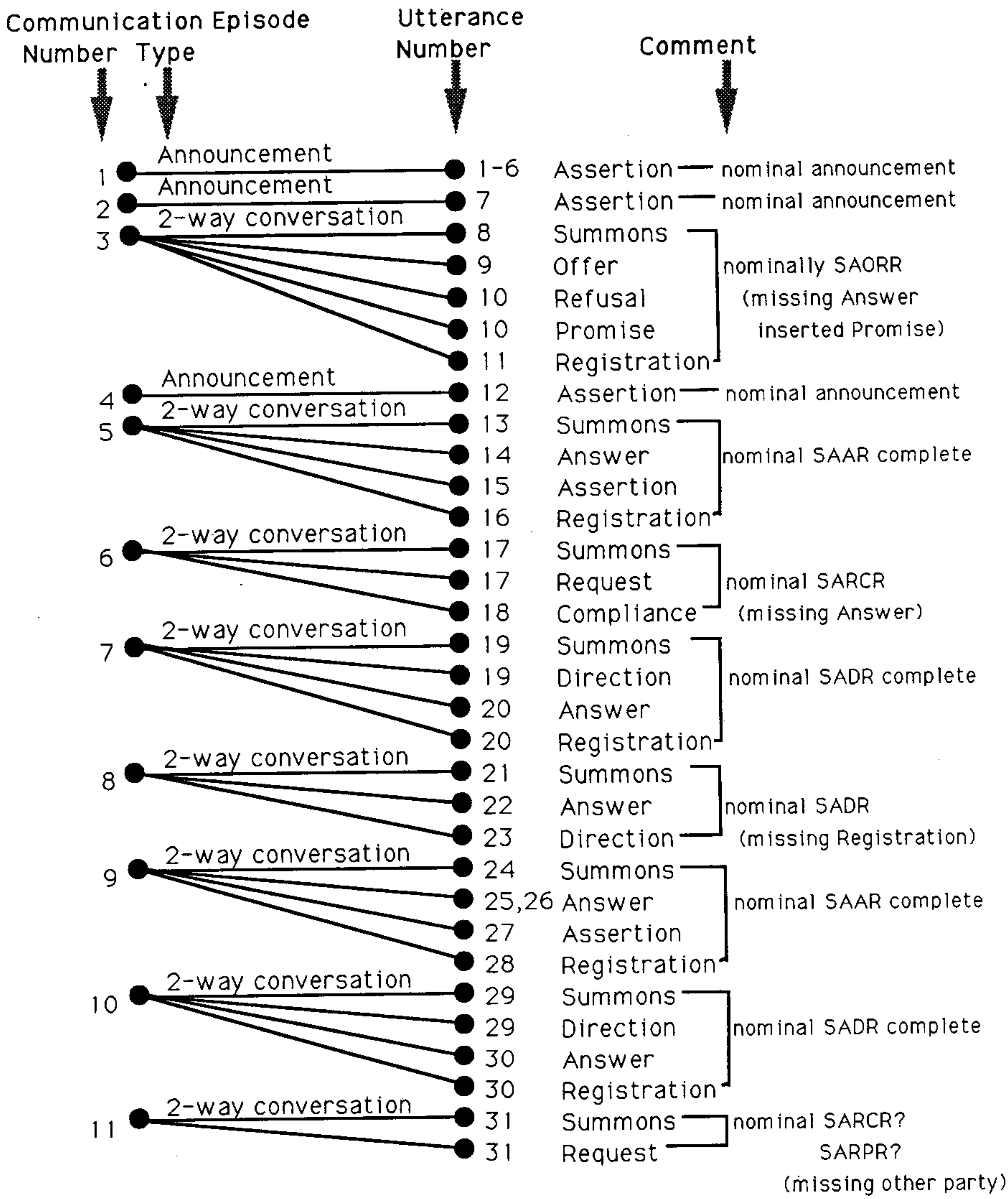


Figure 7. Examples of communication episodes for a portion of the OIS communications

Request/Compliance/Registration or Request/Promise/Registration. The other 3 were not strictly classifiable under this scheme, but fit into the spirit of the analysis: one was nominally an Offer/Refusal/Registration but the refusing party promised to make a request at a later time, and 2 others were nominally Request/Compliance/Registration but the complying party first registered the request and then immediately complied. Figure 7 shows a diagram of some of these communications with the breakdown into episodes (announcements and conversations) and information exchanges.

The component messages of information exchanges (Summons, Answer, Request, etc.) are called *speech acts*. For each of these speech acts, we have determined the nominal *form* of the speech act, the *preconditions* for that speech act to occur in the OIS communication, and the *postconditions* existing in the discourse situation after the speech act has occurred (Appendix 2). The form includes typical types of illocutionary acts (e.g. *commissives*, which commit the speaker to perform some future actions, or *assertives*, which express beliefs) that make up these messages, specific commonly used words or phrases, and necessary or optional content. The preconditions are what the speaker must believe about the state of the communication channel and the launch situation before uttering that speech act is warranted; there is no guarantee that these conditions actually exist in the world, simply that the speaker believes they do. The postconditions do exist in the world prior to the occurrence of the speech act. The form, preconditions and postconditions for OIS communication distinguish the use of these speech acts from the use of similar speech acts in other discourse situations with other characteristics (e.g., different bandwidth like face-to-face communication, different roles like teacher/student or doctor/patient).

We combined the structure evident from the analysis of the discourse situations, conversations, information exchanges, and speech acts, with the information in the OMI and our knowledge of the NTD's task, to infer a goal hierarchy for the OIS communications. At the top of the hierarchy is the goal to launch the space shuttle. This goal can only be fulfilled when all of the sections in all the sequences of the OMI are accomplished. Our study focuses on the particular sequence used after T-20 minutes, Sequence 16, which is made up of 317 sections (15 of which are for contingencies only, not executed under normal conditions). These 317 sections cover 1132 steps, which are the smallest units of work to be handled by the launch team. Many steps can be completed with a single communication episode, but some require a series of conversations about the same topic. Considering the simplest case (one communication episode completes one step), in any one communication episode, the goal of the first speaker is usually to complete a step. If that goal is met, the step is complete; if it is not, the step is said to be *advanced*. For example, consider the conversation and excerpt from the OMI in Figure 8.

Speaker	Message	Speech Act
NTD:	SRO NTD, 212	Summons
SRO:	NTD SRO go ahead sir	Answer
NTD:	Verify if 70 minute jimsphere has normal track	Request
SRO:	Yes sir, it has normal track	Compliance
NTD:	Copy	Registration

SEQ	TIME	CMD	RESP	DESCRIPTION	VERIF.
16-0960	-15M00S I-25M00S	NTD 212	SRO	VERIFY 70 MIN JIMSPHERE HAS NORMAL TRACK	

Figure 8. Conversation and OMI excerpt for step 16-0960.

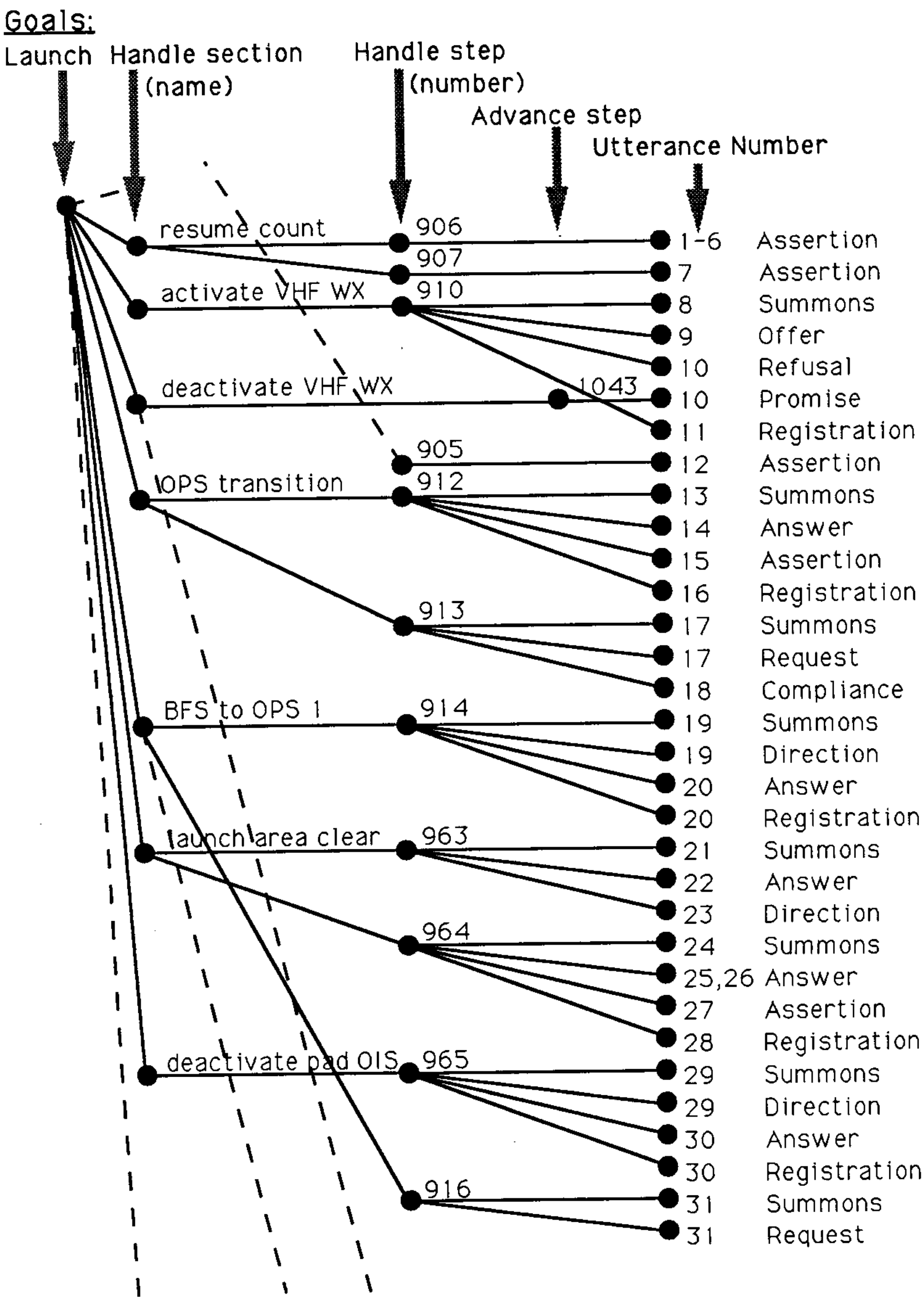


Figure 9. Goal structure of a portion of the OIS communications

The goal of the NTD is to obtain compliance with his request for information, and, in this case, SRO complies immediately with the necessary information; the registration ("copy") completes the step. Alternatively, if the SRO did not have this information available, he would have promised to provide it when it became available some time in the future. This would not have completed the step, but advanced it. In our preliminary study the only communication episode that advances a step is a conversation in which a Promise speech act appears. On the other hand, a step can be completed with any of the types of communication episodes: announcements, polls, conversations, etc. Conversations that complete a step contain at least one of the information exchange types other than Summons/Answer, which is common to all conversations, and Request/Promise/Registration.

As our earlier problem behavior graphs showed, steps can be handled out of sequence, and several sections are often begun but not completed at any one time. In addition, several steps could be advanced or completed within a single conversation, but the completion of any particular step occurs in a single conversation. Figure 9 displays the goal structure as it is traversed in OIS communication. This communication segment begins with two assertions that complete steps 16-0906 and 16-0907, which complete the section RESUME COUNT. The conversation completing step 16-0910 also contains a promise that advances step 16-1043 and opens the goal of completing the section that contains that step. In all, this small segment of communication, approximately 2 minutes, initiates and completes goals to handle 11 steps, advances 1 step, completes 5 goals to handles sections and leaves 2 section goals active for completion in the future.

As presented, this goal hierarchy contains the goals of the entire launch team, and describes communications on the OIS for all members of that team. However, any one individual's goal hierarchy is probably similar to the team's hierarchy. For instance, this goal hierarchy and the explicit description of the pre-and post-conditions for each of the speech acts applied to a particular conversation clarifies some of the deviations from the nominal form of a conversation. In one communication episode, the NTD says, "Houston Flight NTD, perform BFS preflight uplink loading", and FLT replies, "In work". This is nominally encoded as Summons/Answer then Direction/Registration, but the answer to the summons is missing from the conversation. The missing answer can be explained as follows. The goal of the NTD is to complete step 16-0933. Completion of this step requires that Houston Flight receive the direction to PERFORM BFS PREFLIGHT UPLINK (as written in the OMI) and commit to doing it, and that the NTD knows that Houston Flight received and commited to performing this step. Assuming that all the pre-conditions are met, the chain of post-conditions for the nominal structure of a conversation that completes this step result in just those conditions in the world (Figure 10a, refer to Appendix 2 for complete details). With incomplete information exchanges, the preconditions help establish the desired state. A precondition of a registration of a direction is that the registering party be authorized to carry out that direction. The OMI shows that only Houston Flight is authorized to carry out the direction; the fact that a registration was provided at all implies that the pre-condition was met, and that FLT is indeed the registering party. Thus, the post-conditions imply that the desired state was achieved (Figure 10b).

Since an answer is not required for completion of the goal, including an answer in the conversation may seem inefficient and the question as to why it is used at all (as opposed to why it is NOT used, occasionally) may be raised. Our surmise is that the inference process required when an answer is not used is perceived to be less reliable than the simple recognition of post-conditions necessary in an complete exchange. The necessity of high reliability in the launch procedures has influenced the communication culture, producing a preference for highly reliable conventions for conversation. In this preliminary analysis,

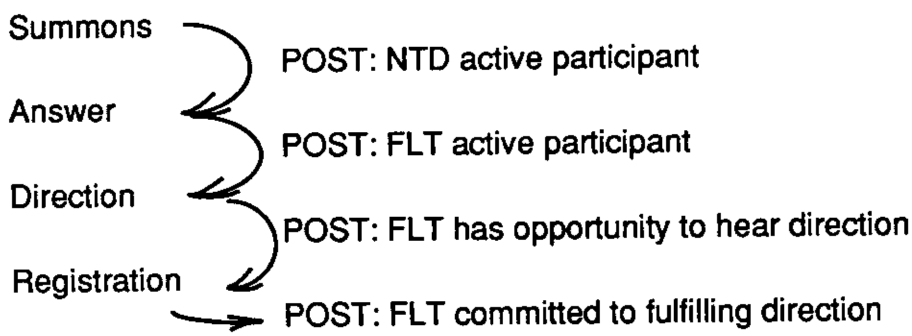


Figure 10a. Logic chain through a complete information exchange

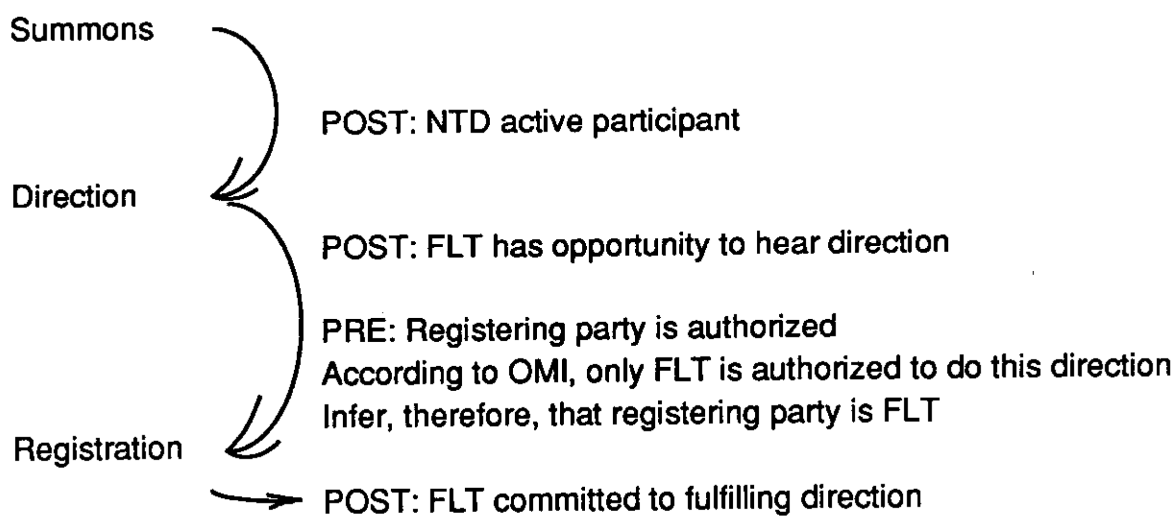


Figure 10b. Logic chain through an incomplete information exchange

Figure 10. Logic chains through speech acts that accomplish a goal with complete and incomplete information exchanges.

27% (23) of the 85 information exchanges are incomplete (in 13 of the 36 conversations studied). Of the 13 conversations, 4 conversations (representing 4 incomplete information exchanges) are missing only an answer to a summons like the example above and complete the goal of the conversation in spite of the incomplete. Five conversations (representing 12 incomplete information exchanges) are missing an entire side of the conversation. Another 4 conversations (representing 7 incomplete information exchanges) are missing the final registration in the conversation, so that the completion of the goal is not assured. These incompletions are yet to be explained.

The goal structure can also be used to understand some of the fine detail of the OIS communications. For instance, in the segment of OIS communication we studied, there were 73 referents to be resolved. The resolution of all of these referents present no problem to the participants because there are no exchanges to clarify referents (e.g. there were no exchanges like S1: "Copy that", S2: "What was that you copied?"). A possible explanation for the ubiquitous ease of referent resolution may be that referents usually refer to things within a single goal. Of the 73, over 80% (60) are resolved within the confines of the current conversation in service of a single goal. Only 2 are resolved by reference across a conversational boundary, and both of these are within the completion of a single goal (a step requiring multiple conversations). An additional 3 referents are resolved from visual information in the OMI related to the step that is the current goal. Of the 8 resolutions requiring knowledge outside the current step-handling goal, 4 occur in conversations about the amplitude of the shuttle pilot's communication channel and refer to the amplitude of an utterance, 1 is a reference to "today" which requires general world knowledge, 2 refer to the previous speaker in the same conversation although there is a change of step-handling goal, and the remaining 1 requires an understanding of the mode of communication (i.e., in "I did not copy your last", "last" refers to the last verbal message uttered by the partner in the conversation). Since the resolving information is almost always available within the same goal, the goal structure may be an aid in resolving referents.

The analysis of these data in light of the task of launching a space shuttle, have produced categories of discourse situations, conversations, information exchanges, and speech acts and an inferred goal hierarchy that connects them. From these emerge an instantiation of Grice's maxims of cooperative communication applied to the particular domain of OIS communication shortly before a space shuttle launch. This instantiation can be expressed as follows (adapted from the description of Grice's maxims in Clark, 1984). (Throughout the OIS maxims below, the terms in all upper case refer to the contents of those columns in the OMI: CMD refers to the person who initiates the communication, RESP refers to the person who receives the communication, SEQ refers to the step number, DESCRIPTION refers to the description of the step, etc.)

Grice's Maxims

Cooperative principle
Make your conversational contribution such as is required, at the stage at which it occurs, by the accepted purpose or direction of the talk exchange in which you are engaged.

1. The maxim of quantity
a. Make your contribution as informative as is required (for the current purposes of the exchange)

OIS Maxims

OIS Cooperative principle
Make your contribution to the launch preparation, as soon as is safely possible, as written in the OMI.

1. The maxim of quantity for the OIS
a. Make your contribution as informative as is required

i. assume the person to whom you are speaking can reference the correct step in the OMI either by its SEQ or by its DESCRIPTION, so communicate either the SEQ or DESCRIPTION in each exchange.
ii. assume the person to whom you are speaking cannot reference the correct step in the OMI with just the CMD, RESP, or TIME, so do not use any of these as a sole reference point.
iii. since OIS communication is audio-only, the listener must inform the speaker verbally that his or her message was received and understood. Therefore, answer each summons and register each message.

b. Do not make your contribution more informative than is required.

b. Do not make your contribution more informative than is required

i. do not communicate both the SEQ and DESCRIPTION.

ii. do not communicate the TIME unless explicitly specified in the DESCRIPTION of the step.

iii. all communication is over Channel 212 at this time in the countdown, and everyone knows this, so do not communicate the CHANNEL.

iv. since the communication is only verbal over the OIS, the CMD should communicate both who he or she is and to whom the information is addressed (the RESP), as written in the OMI.

2. The maxim of quality:
Try to make your contribution one that is true.
a. Do not say what you believe to be false.
b. Do not that for which you lack adequate evidence.

2. The maxim of quality for the OIS:
Try to make your contribution one that is true. (unchanged from Grice's maxims)
a. Do not say what you believe to be false.
b. Do not that for which you lack adequate evidence.

3. The maxim of relation:
Be relevant.

3. The maxim of relation for the OIS:
Be relevant.

i. information from a CMD is only explicitly relevant to the RESP, as written in the OMI.

ii. Since the communication is only verbal across the OIS, a CMD should *summon* the RESP and receive an *answer* to ensure that the relevant person is actively listening, before passing the information.

4. The maxim of manner:
Be perspicuous.
a. Avoid obscurity of expression.

b. Avoid ambiguity.

c. Be brief (avoid unnecessary prolixity).

4. The maxim of manner for the OIS:
Be perspicuous.
a. Avoid obscurity of expression.

i. when saying the DESCRIPTION of a step, use the words written in the OMI, or a very close approximation.

b. Avoid ambiguity.

i. do not say the DESCRIPTION of one step and the SEQ of another step in the same turn, because the RESP may think you are confusing the two as one.

c. Be brief (avoid unnecessary prolixity).

i. when saying the DESCRIPTION of a step, use only the words in the OMI, or a very close approximation, do not embellish.

d. Be orderly.	**d.** Be orderly. **i.** communicate the completion of a step as soon as it is complete, or, if several steps are related under a single section in the OMI and are completed within a short time of each other, wait until the group is complete and then communicate the completion of all the related steps. **ii.** when giving the completion of several steps, give them in chronological order.

As with Grice's maxims for general conversation, the OIS maxims are not inviolate. For instance, the NTD routinely includes the channel number when he makes a summons although it is more informative than is necessary for the T-20-min-to-launch OIS communication situation (because all communication is on Channel 212). Prior to T-20 min, communications happened on many channels, and indeed, it is part of the NTD's job to direct conversations to different channels. Thus, changing communication situations dictate changing maxims. Communication styles from one situation may be carried into another situation without disruption of the cooperative principle, although they may violate small points in the relevant maxims.

The OIS Cooperative Principle and related maxims of conversation give prescriptions about what content to communicate, when to communicate it, and what words to use to convey that content. These, together with the inferred goal structure, the speech acts, information exchanges for this portion of the countdown, the form of conversations, and discourse situations, provide much information that could be used in constructing a computational model of the NTD and evaluating the design of computer support aids. This information presented here is tentative, in that it is derived from a preliminary discourse analysis of only 15 minutes of communications. Before using this information extensively in modeling or design evaluation, further work must be done to confirm the validity of these results: analysis of a greater portion of communication, investigation of non-routine OIS communications to determine if and how the OIS maxims are violated or changed (e.g., during launch simulations where many problems are encountered), differences in the maxims with for different launch situations (e.g., prior to T-20 min and after T-20 min) or launch team members, experiments to validate the maxims with real NTDs, and comparison to other discourse situations to more fully understand the unique character of the OIS communication task. However, a preliminary version of a computational model, with rudimentary incorporation of some of the results of this discourse analysis, is proposed for discussion in the next section.

5. THE COMPUTATIONAL MODEL: NTD-SOAR

We are using our understanding of the NTD's task to build a computational model of the of the NTD. That is, we are designing a computer program that will mimic the NTD's behavior in many situations, reproducing the functions the NTD performs, in the same amount of (simulated) time, within human perceptual and information processing capabilities. Our model currently views the NTD as an individual information processing agent. This agent gets inputs from the environment, primarily the presentation of information through verbal communication and visually from the OMI, and produces outputs that effect that environment, primarily saying information over the communication channels and writing notes in the OMI. The agent's outputs are produced in the service of goals, through operators that manipulate symbolic representations of elements in the environment. The choice of operators and the sequence in which they are used are constrained by the agent's knowledge, including knowledge of the environment, of desired states for the environment, of mechanisms for change, and of communication (OIS maxims). The current version of the model performs the routine cognitive skills involved in performing non-problematic communications on the OIS, finding the appropriate location in the OMI, and checking off steps in the OMI as they are complete. Such a computational model of routine cognitive skill, where performance is driven by goals and implemented with operators constrained by knowledge, is one in the family of GOMS models often used in HCI research (Card, Moran & Newell, 1983; Olson & Olson, 1990).

Our first few versions of this model will assume that the information coming into the NTD comes in perfectly, that is, the model's perceptual system will make no errors in perceiving information. Likewise, the first few versions of the model will assume that the information flowing from the model will be executed perfectly, that is, the model will not mix up words in its speech, hit an unintended button, or cross out the wrong step in the OMI. Eventually, we expect to model perceptual errors and action slips, but it is important to get the model working correctly with perfect information before attempting to assess the effects of imperfect information.

The model also does not take into account the source of information, that is, it does not attach any meaning to a piece of information attributable to its source, rather than its content. Thus, all sources are treated as equally accurate, equally trustworthy, equally timely, etc. This is true of human sources of information as well as inanimate sources of information. For the most part, this is a reasonable assumption for the initial computational model because the parties authorized to complete each step are recorded in the OMI and, in the vast majority of cases, the OMI is followed to the letter in this regard. In the hour of communications studied, we have only seen one instance of a message uttered by a person unauthorized to do so. In that case (utterance 6 in Appendix 1), CGLS says "T-20 minutes and counting" which usually completes step 16-0907. However, only NTD is authorized to complete that step, and he does so immediately, saying "Step 907 verified complete". Since this type of exchange happens so rarely, we have chosen to ignore it for the purposes of a baseline computational model.

Our GOMS model of the NTD is built within the Soar unified theory of cognition.[2] We will first present a brief overview of the Soar unified theory of cognition, and then a description our preliminary model, NTD-Soar.

5.1 A Brief Overview of the Soar Unified Theory of Cognition:

Soar is a recent attempt to provide an architecture for human cognition (Laird, Newell & Rosenbloom, 1987; Newell, 1990). Soar is given in the fashion of a programmed computer, with data structures, memory accessing organization, and full details of the operation of the processors. Thus, one can specify the contents of Soar memory structures for particular users in particular task situations. These contents, in effect, program Soar so that it produces simulations of the behavior of the user in the task.

As succinctly described in (Lewis, et al., 1990) and in more detail elsewhere (Laird, et. al., 1987; Newell,1990), the Soar architecture formulates all tasks in *problem spaces*, in which *operators* are selectively applied to the *current state* to attain *desired states*. Problem solving proceeds in a sequence of *decision cycles* that select problem spaces, states and operators, resulting in the application of the operator to move to a new state in the space. Each decision cycle accumulates knowledge from a *long-term recognition memory* (realized as a

---

[2] See John, Vera, & Newell, 1990 for a discussion of the relationship between GOMS and Soar.

production system). This memory continually matches against *working memory*, elaborating the current state and retrieving *preferences* that encode knowledge about the next step to take. Access of recognition memory is involuntary, parallel, and rapid (on the order of 10 msec). The decision cycle accesses recognition memory repeatedly until *quiescence*, when no more knowledge can be brought to bear; then the decision is made about which step to take next. Each decision cycle takes on the order of 100 msec.[3]

If, at quiescence, the accumulated coded knowledge in working memory is insufficient (or conflicting), so that Soar's next step cannot be determined, then an *impasse* occurs. Soar responds to an impasse by creating a *subgoal* in which a new problem space can be used to acquire the needed knowledge (or resolve the conflict). If, similarly, lack of knowledge prevents progress in this new space, another impasse occurs and another subgoal is created -- and so on, leading to an entire goal-subgoal hierarchy. Once an impasse is resolved by problem solving, the *chunking* mechanism adds new productions to the recognition memory that encode the results of the problem solving. Thus, the impasse is avoided in the future, because these productions provide the appropriate knowledge immediately.

Soar interacts with the external environment through perceptual and motor processes, which operate through the working memory. Incoming perceptions are added to the current state in the top problem space and motor commands are made part of this current state. The interactions occur asynchronously with the operation of the cognitive decision cycle.

Soar is sufficiently complete and plausible for human cognition to be used to model and explain many diverse cognitive phenomena (Lewis, et. al. 1990; Newell, 1990). Examples include natural language comprehension, problem solving, immediate reasoning, perceptual search, strategy discovery and change, and the taking of instructions. These tasks encompass the major dependent variables of interest in HCI -- time, errors, and learning rates.

5.2. The Structure of NTD-Soar

From the observation, interviews, descriptive and discourse analyses of the NTD's behavior detailed above, we posit that the NTD's job requires three types of activities: 1) routinely following a procedure in the OMI, 2) handling an anomaly from standard procedure, and 3) updating an internal model of the the state of the space shuttle, its associated systems (e.g., launch pad), and the countdown. Each of these will be discussed briefly to clarify what we mean by these terms and from what data we inferred them.

The bulk of the observed behavior is explicitly involved in following procedures in the OMI. When the NTD is summoned, he answers and enters into an information exchange as described in Section 4. That information exchange directs him to the relevant step in the OMI, where he takes appropriate action (e.g., checking of a completed step, filling in required information). When that conversation complete, the NTD either receives another summons, or he looks ahead in the OMI and initiates communications to complete the next step in which he is involved. This behavior seems to be a routine cognitive skill, a local response to incoming auditory information or information written in the OMI. The information exchanges in this routine part of his task have well-known nominal formats, and are not difficult for the NTD to perceive or understand. Unlike some anomalous situations that may arise during countdown, when the launch is progressing smoothly the

---

[3] The recognition memory access time and decision cycle time given are estimates of how long these processes would take in the human information processor, not the real time for a computer simulation of those processes to run (current computer technology is much slower).

NTD does not seem to be involved in any problem solving, difficult comprehension of ambiguous information, or interpretation of goals; he is simply following a procedure at which he has become expert.

For example, consider the following short exchange between the NTD and Flight (FLT) at Johnson Space Center (responsibility for the shuttle transfers from KSC to FLT immediately after a launch, but the two centers are in constant communication during the countdown). The numbers indicate start and end times of the utterance in seconds.

20.593	21.533	NTD:	Houston Flight,
21.666	22.080		two one two,
22.080	23.866		we got a requested weather briefing at this time.
25.267	28.184	FLT:	We will not need that one. We'll have an update at T-9.
28.448	28.750	NTD:	Copy.

This exchange occurs just after the countdown has resumed at T minus 20 minutes (following a ten-minute built-in hold). After confirming the resumption of the countdown over the public address system (step 16-0907, Figure 2), the NTD looks through the OMI for the next step in which he plays a part, step 16-0910 on the next page. The step is an optional weather briefing, to be requested by FLT. When the NTD does not receive a request from FLT, as he expects from the procedure written in the OMI, he checks with FLT as to whether the step is to be performed. FLT responds that it is not.

To model this exchange, NTD-Soar, perceives via simulated audio input that the count has resumed at T minus 20 minutes and matches the content of that announcement to the content in the OMI DESCRIPTION column to place itself at the right location in the OMI (OIS maxim 1.a.i) NTD-Soar then searches the OMI to find out what he needs to do next. It finds that step 16-0910 is the next step in which the NTD is involved and reads the information associated with the step. It reads that the step is still pending, and that FLT is due to say whether it will be performed. NTD-Soar forms the goal to complete the step. NTD-Soar then hails FLT (via simulated speech output), according to OIS maxim 3, with a Summons of the form shown in Appendix 2. It then orients FLT to the step in question by saying a close approximation to the DESCRIPTION of that step in the OMI (OIS maxims 1 and 4c), indirectly offering the weather information. On hearing FLT's refusal, NTD-Soar crosses off the step as not required (via simulated hand action), and acknowledges FLT's refusal by saying "Copy" (OIS maxim 1a). It finishes the task, by crossing off the remainder of the steps in the subsection since they are only necessary if the weather briefing has been requested.

Occasionally, an anomaly occurs and the launch process deviates from the procedures in the OMI. Anomalies range from mild, well-understood problems, to crises that force a return to a previous point in the countdown, a scrub of the launch, or emergency procedures. Many anomalies have been thoroughly analyzed ahead of time, so that procedures for handling them are printed in books similar to the OMI. In these cases, the handling of the anomaly is similar to following an OMI procedure; it involves finding the correct place in the correct book and following the procedure for that situation. When the anomaly lies outside the range of what has been previously thought through, the NTD seems to be gathering necessary information and then following well defined procedures, or if no procedures exist after all information is exhausted, calling for a scrub of the launch. We determined this part of the task analysis from interviews with the NTDs and with the training team member who performs the launch simulations for NTD training purposes.

In the course of following the procedures in the OMI, the NTD seems to acquire, and is able to access, immense amounts of information about the state of the shuttle systems and the countdown process. Evidence for this is that the NTD does not only respond to the incoming information or go to the next step in the OMI, but he also initiates steps out of order, calls for information about incomplete steps, and flips pages well ahead of the current information during slow times on the communication channels (observed with videotapes). We infer that these behaviors reflect at least two types of information: information about the physical state of the shuttle and associated systems (e.g., whether the launch pad is cleared of personnel, whether the liquid hydrogen fuel has been loaded, etc.), and information about the timecourse of the launch countdown (e.g., whether procedures that must be done within a certain time of each other are progressing apace, whether the current progress of the countdown will allow the launch to occur during an acceptable time determined by satellites passing overhead or approaching weather, etc.). There is too much information to be held in the NTD's working memory, so we assume it is stored in long-term memory or external memory (e.g. the log book). The NTD probably constructs and maintains a "mental model" of the state of the shuttle, its subsystems and the countdown, that allows him to access and reconstruct the information necessary to perform his job. The information in this mental model affects how the OMI procedures are followed, and the information gotten by following OMI procedures effects what's in these models. The current version of NTD-Soar does not yet include the mechanisms for producing these model updates from the local OMI procedure following. However, several approaches to this learning-by-doing have been explored in other Soar systems (Lewis, 1991; Young, 1991) and we expect to be able to modify these approaches for our task.

6. DISCUSSION

We have described of the NTD's job and some analyses of observed auditory communications. We have also presented a computational model of the portion of that job that involves routine, skilled performance. Here, we will demonstrate how such a model can be used to evaluate hypothetical computer support systems, both with regards to the NTD's individual performance and the entire launch team's performance. We will then examine the value added to the computational model by the discourse analysis and speculate as to how discourse analysis could be used in design.

6.1. *What-if* Evaluations on the Individual Performance Level

NTD-Soar currently performs the routine cognitive skill of following procedures written in the OMI. It uses simulatied auditory input and knowledge of the organization of the OMI to locate the correct place in the OMI and perform the appropriate action (crossing off a completed step, filling in a write-in section, etc.). We believe that this routine cognitive skill is but one aspect of the NTD's performance, with the more global issues of understanding how each completed step advances the shuttle system and the countdown being even more important than these routine interactions. Therefore, we believe that the model must integrate the local performance issues with the global understanding before any complete evaluations of changes to the NTD's computer support systems can be made. However, the current model of local performance is sufficient to demonstrate one possible style of evaluation that provides information about the relative efficiency of support systems with respect to performance time.

Consider the following two exchanges (Figure 11) between the NTD and the entire launch team over the public address system (PA) and, seven seconds later, the exchange between the NTD and Houston Flight Control (FLT) about the weather briefing examined previously.

Utt.no.	Start (s)	End (s)	Speaker	Channel	Utterance
u7	12.009	13.347	NTD:	PA	Step 907 verified complete
u8	20.593	21.533	NTD:	212	Houston Flight,
u9	21.666	23.866			two one two we got a requested weather briefing at this time.

SEQ	TIME	CMD	RESP	DESCRIPTION	VERIF.
16-0910	-20M00S COUNTING	*FLT 212	NTD	WEATHER BRIEFING REQUESTED BY *FLT.	34-01
		NTD 212	STM JYES	YES ____ NO ____	

Figure 11. Conversation and OMI excerpt for step 16-0910.

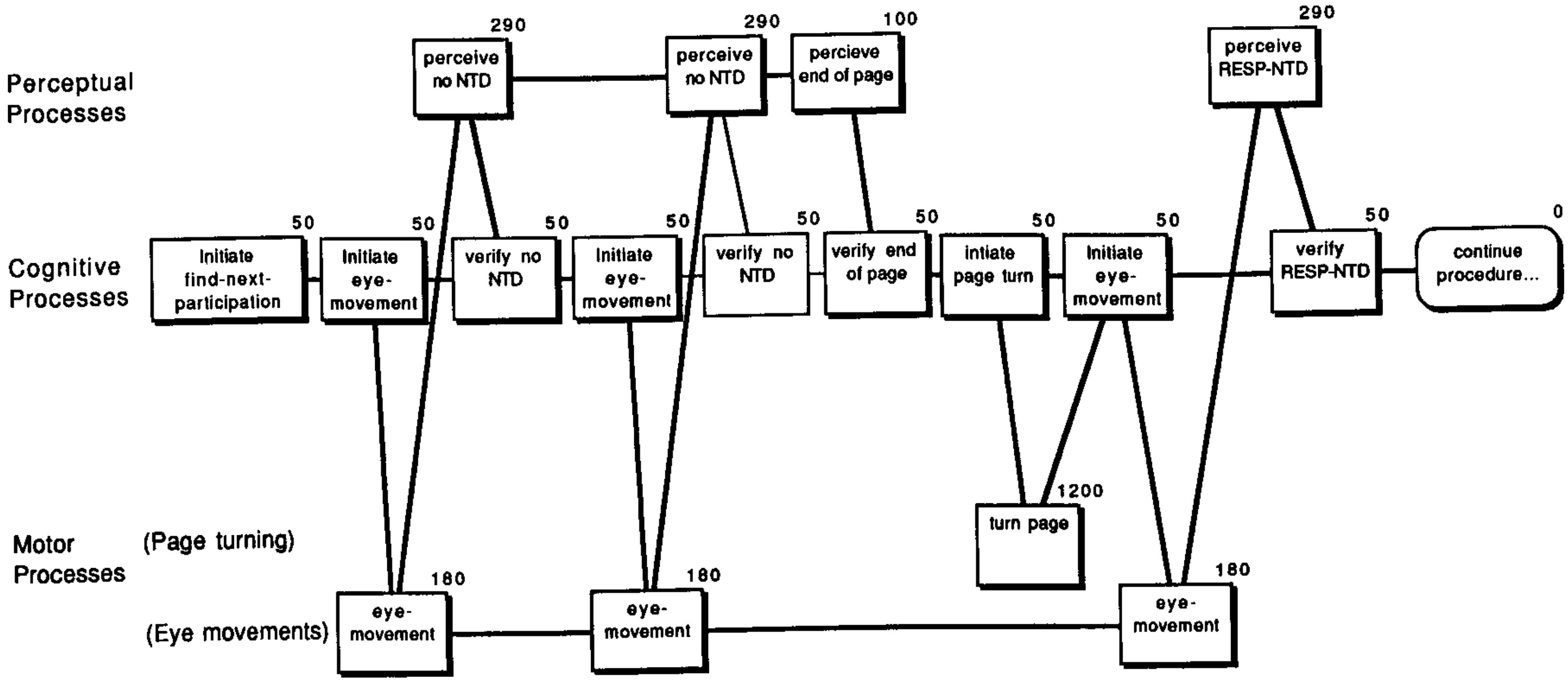
Prior to these exchanges, the countdown was restarted at T-20 minutes and u7 represents the NTD completing his responsibility for step 16-0907 by stating that fact over the public address system and crossing off that step in the OMI. The next role for the NTD is on the next page in the OMI (Figure 11). The NTD is listed as the RESP, the person who receives the call, on a call from FLT in which FLT requests a weather briefing. However, instead of being the RESP as is written in the OMI, the NTD initiates the call to FLT and offers the weather briefing. We model this behavior in NTD-Soar with a Get-Next-Participation operator that scans the CMD and RESP columns in the OMI from the point of the last participation (in this case, where the NTD marked off step 16-0907 on the previous page) to the next place where the NTD is either CMD or RESP. When the next participation is found, NTD-Soar then looks at the associated time of the participation. If the time is the same as the present countdown clock, NTD-Soar initiates a summons to the other participant, irrespective of whether the NTD was the intended initiate or the intended receiver in that step. After the NTD's summons is answered, if the NTD is the CMD, NTD-Soar gives the step content printed in the OMI. If the NTD is the intended RESP, as in this example, NTD-Soar gives the step-content printed in the OMI in the form of an offer, notifying the intended CMD that the NTD is prepared to complete the step.

The scanning behavior leading up to the exchange with FLT currently involves scanning down columns in the OMI, looking for the initials "NTD", and turning pages. The activities associated with this behavior can be represented in a critical path method (CPM) schedule chart, Figure 12. The CPM chart shows the operations in the model that seek and find the next point of NTD participation. Each box represents a perceptual, cognitive or motor process (lined up horizontally), and each line represents an information dependency between the processes. These processes proceed sequentially or in parallel, as dictated by the information dependencies. For example, there is a dependency line between the cognitive process that initiates an eye movement and the motor process that performs the actual eye movement, because the deliberate movement cannot occur before the intention to move has been formed. Each process is assigned a duration, in ms, appearing above the upper right corner of each box. These durations are estimated from previous research and the actual content of the process. From these time estimates and the information dependencies, the critical path (the total time for all the processes to be complete) can be calculated. In this case, all the processes proceed serially and the total time is 3110 ms.

This model of the scanning behavior can now be used to evaluate a different interface to the information in the OMI. As an illustration, imagine an on-line OMI, where the sequences in the OMI are reproduced on the CRT screen with the same columnal formatting as in the paper version. Imagine also, a function key that puts the next sequence in which the NTD participates at the top of the screen. Then, instead of scanning down columns and turning pages to find his next participation in the countdown, the NTD moves his finger horizontally until it is over the correct key and presses the key. After some system delay, the display changes, putting the NTD's next sequence at the top of the screen. The interaction with this interface, from the point where the intention to find the next participation sequence is formed until the point where the NTD recognizes that he has access to the information he desires, is represented in the CPM chart in Figure 13. With this interface, the eye-movement to the standard place on the computer screen can be done in parallel with waiting for the display to be presented, and the total time to find the next point of NTD participation is 890 ms plus the system response time of the computer support system.

The two CPM charts can now be compared and several *what-if* evaluations can be made. For example, in this particular scenario, the next point of NTD participation is three steps and one page away from the previous point of participation. Given that scenario, the on-line support would need to have a system response time of less than 2220 ms (3110-890 ms) to be used as quickly as the current OMI. What if the average distance between steps requiring NTD participation were only 2 steps and included a page turn only half the time? Then the average OMI critical path would have one less eye-movement and perception and a page turn only half the time and the average total time would be 2080 ms. Therefore, the system response time for the computer tool would have to be less than 1190 ms to be as effective. What if further analysis revealed that the NTD used not only the specific information in the sequence in which he was participating, but he also used a sense of the *distance* between the current step and the next step, in understanding the status of the countdown. A computer-support application designer might then consider using animation to simulate the information passing in front of the NTD's eyes as he scans through the current OMI, to provide continuity of information and the necessary distance information. Research into animation in information display indicates that a transformation from one information state to another should take about a second; if it is much shorter, "the user loses object constancy and has to reorient himself. If [it is] much longer, then the user gets bored waiting for the response" (Card, Robertson & Mackinlay, 1991). The CPM chart indicates that a system response time of about a second does not increase the performance time beyond the paper OMI, so animation would be a viable option. The interface designer would then need to determine whether the distance between steps should be represented as a function of response time, as it is with flipping pages and scanning them, or whether the density of information passing before the eyes in a constant amount of time would give the same useful information to the NTD. Further what-if analyses would help in this and other design choices. (An example of such comparisons in actual workstation evaluation for telephone operators is presented in Gray, John, Stuart, Lawrence, & Atwood, 1990.)

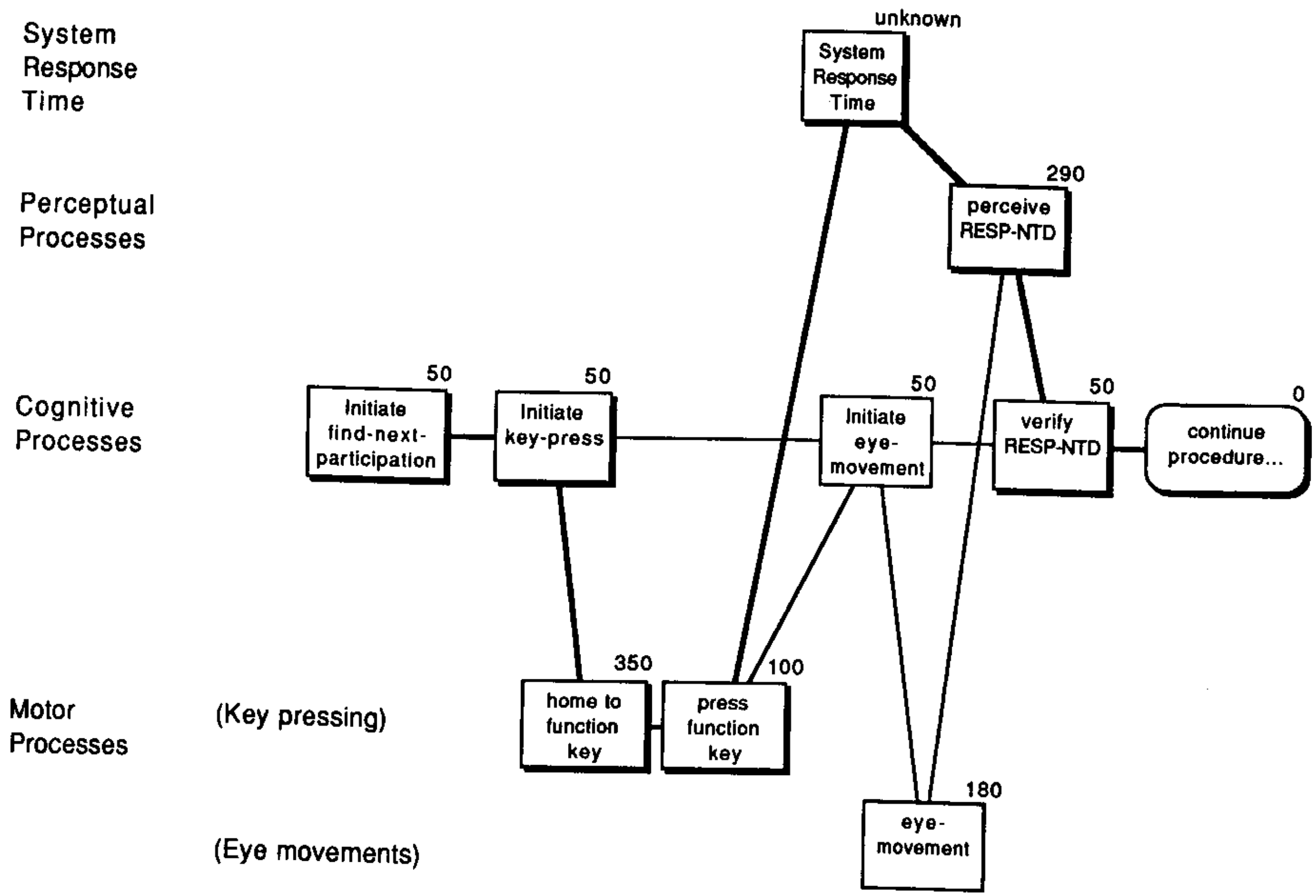
In this illustration, performance time is not the only variable of interest in this system, and it is probably not the most important variable. In fact, the NTD actually pauses a full 12 seconds before initiating the hail to FLT, much longer than the 2.5 seconds necessary to find the next point of participation. Further data collection (e.g. videotapes as well as audio tapes) is necessary to determine whether the NTD is filling the interval with other time-critical tasks, recording information for future use, looking further ahead, etc., or simply waiting for FLT to initiate the request himself before initiating the offer. Under the former conditions, the response time of a system may be important to allow the NTD the slack time



Total time necessary between completion of step 16-0907
and the NTD finding the next step that requires his participation = 3110 ms.

Figure 12. Processes required for the NTD to scan the OMI for the next step in which he participates, after completion of step 16-0907.

(Estimates for the duration of perceptual, cognitive, and eye-movement operators are taken from John, 1990. The estimate for the turn-page operator duration is from Egan, 1991.)



Total time necessary between completion of step 16-0907
and the NTD finding the next step that requires his participation = System Response Time + 890 ms.

Figure 13. Processes required for the NTD to use a hypothetical computer support system to find the next step in which he participates, after completion of step 16-0907.

(Estimates for the duration of perceptual, cognitive, and motor-movement operators are taken from John, 1990.)

to pursue the other tasks he is accustomed to perform in this timeframe. In the latter case, system response time would not be on the critical path for the larger procedure and would not be as important. In either case, it is a good rule of thumb to ensure that any new system not be worse in any measure than the current paper OMI, and this type of analysis is useful in evaluation of performance time for a proposed system.

6.2. Organizational *What-If* Evaluations

The NTD is an important individual in the coordination of a shuttle launch, and a computational model that can be used to evaluate computer support systems for his individual tasks, as described in section 6.1 is a contribution to the design of those support systems. However, the NTD is only one member of large team where every member's performance has an impact on the launch. Any computer support system introduced into the launch procedure will most likely be used by many members, not simply to support the NTD's individual tasks. Therefore, it is appropriate to ask whether a computational model like NTD-Soar can help evaluate the impact of computer support aids on the performance of the entire team, rather than just the performance of the NTD alone.

Research by a group of social scientists, organizational behavior researchers, and computer scientists, with another Soar system, called Plural-Soar, indicates that linking together several simulated intelligent agents and giving then a task to do collectively, can lead to the emergence of recognizable organizational behavior phenomena (Carley, Kjaer-Hansen, Prietula, and Newell, 1991).

Plural-Soar's task was to fill a series of orders in a warehouse, and the researchers varied the number and capabilities of the agents. The number of agents varied from one to five. The least capable agent, the basic agent, could perform the order-filling task without any memory for the location of objects nor any communication capabilities with which to interact with the other agents. The most capable agent could remember where objects were located in the warehouse and broadcast questions to the other agents and receive answers as to where objects were located. The researchers then played what-if on an organizational level, discovering the effects of number of agents and capabilities on several organizationally interesting performance measures. These simple agents reproduced several well-known organizational results including that time to complete the task showed a non-linear decrease with the number of agents (decreasing returns to scale), cognitive and physical effort per agent showed a non-linear decrease with the number of agents (there was overhead involved with dealing with the other agents), and the waiting time increased with the number of agents (they got in each other's way).

Although Plural-Soar's task and simulations of the individual agents were very simple, the results are indicative of the kind of organizational phenomena that can be investigated using that approach. NTD-Soar, with its access to external memory for the situation, that is, the marked-up copy of the OMI, and its ability to accept simple communications from launch team members ("step 16-0910 complete") is comparable to Plural-Soar's most capable agent. The researchers discuss several directions in which such an agent could be further specified to produce opportunities for more interesting social behavior to emerge. Among the directions discussed are more situation knowledge, learning from experience, and more sophisticated communication capabilities. All of these are on the agenda for NTD-Soar.

6.3. Speculations about using discourse analysis in the design of computer support systems for the NTD

The preliminary discourse analysis presented here has provided information about discourse situations, conversations, information exchanges, speech acts, OIS maxims of cooperative communication and a goal hierarchy. However, models of other tasks with large conversational components have been successful in evaluating computer support systems without using such analysis (Gray, et. al., 1990); what value does this information add to a computational model of the NTD?

To examine the value added by the discourse analysis, consider a computational model constructed without reference to the conversational behavior on the OIS. A minimally competent model could be constructed using the OMI alone (call it the *OMI-NTD-model*). The OMI-NTD-model would have a goal structure identical to that inferred from the discourse analysis, because that goal structure is also built into the format of the OMI: steps are grouped into sections, sections into sequences, with the ultimate goal being the launch itself. Operators for satisfying the goals in the OMI-NTD-model would be derived from the two-dimensional encoding of information on the written page (scanning operators) and the content of that information. That is, reading operators would match incoming information to specific locations in the OMI, generate messages, and initiate communication episodes in which the OMI-NTD-model plays a part. Such a model would be sufficient for making the evaluation of the computer display system posited in section 6.1.

The OMI-NTD-model, however, would not produce the conversation observed on the OIS. It would be able to generate a summons from the CMD and RESP columns of the OMI, but it would have no knowledge that a conversation should occur; it would proceed from the summons to the message (e.g., a literal reading of the DESCRIPTION of a step) without waiting for an answer to the summons or a registration of the message. It would be a model of communication that assumes all messages are heard and acted upon as soon as they are spoken on the OIS. It would be a model of the NTD in isolation receiving auditory information from, and delivering verbal messages to, an amorphous external entity.

The preliminary discourse analysis produced a much richer model of communication than examination of the OMI alone. The OIS maxims provide knowledge that produces complete conversations. They provide knowledge that allows for variation in message content (e.g., maxim 1.a.i allows either the SEQ or DESCRIPTION to be used in identifying the step targeted for completion) and could produce variable message content constrained by the maxims with a simple random process for selection between alternative forms. Such a model, indeed even its current implementation in NTD-Soar, produces a communication flow much more easily identified with the actual behavior. This level of model, however, cannot produce the violations of the OIS maxims observed in the communications. The information exchanges presented here, with the pre-and post-conditions of the component speech acts, can help understand such variability when it is observed, but they cannot generate that variability. An even richer model of human communication is required for that level of prediction.

The discourse analysis, then, provides additional operators and preferences for operators in our Soar model, beyond what an analysis of the OMI could provide. What role does this richness play in the computational model as a design tool? As stated above, the minimal OMI-NTD-model could be used for the individual what-if analysis of Section 6.1; the discourse information adds nothing to the prediction of the NTD's perceptual, cognitive, and motor processes not directly involved in communication.

The discourse analysis does, however, give information about the assumptions behind communications, which is potentially useful in qualitative evaluation of computer support systems. Every computer support system will have implications for the assumptions of communication described in the OIS maxims and speech acts, and these implications can be weighed against the current technology. For instance, consider a sophisticated computer support system that combined on-line displays of OMI information with limited speech recognition that could pick out the calls-signs of launch team members. (A speech recognition system with limited vocabulary and limited users, with an abundance of training materials in the form of previous launch tapes, is not beyond current technology.) Imagine an interface that allowed a subsystem manager to point to the OMI step he or she wished to report complete to the NTD. The subsystem manager would hail the NTD, the support system would recognize when the NTD answered the summons, and then automatically display the indicated step on the NTD's terminal. Such a system would change the OIS maxims in several ways. For instance, the step number or description would no longer be required verbally (maxim 1.a.i) and conversations may reduce to a summons and answer, followed by the assertion "Complete" and the NTD's registration, "Copy". This interface would also effect the pre- and post- conditions of the speech acts and change the logical chain through information exchanges. The incomplete conversation discussed in Section 4, which was missing only the answer to the summons, could no longer be understood because the computer support system could not bring the NTD to the correct location in the OMI without that answer. We would predict that a summons would always be answered with this system, or the summoner would issue the summons again before proceeding.

This analysis shows differences between discourse situations derived from the technology involved. It does not, however, provide any quantitative measures with which to judge the value of those differences. It also remains to be determined how many such differences could be derived solely from an analysis of the technology involved, without reference to actual behavior with that technology. In addition, the discourse analysis does not give much guidance as to how to design new support systems. (Examining the assumptions in the current OIS maxims and speech acts gives some indication of *what* might be varied, but no guidance as to *how* to vary it with technology or in *which direction* to go.) Much work must be done to bring discourse analysis into the designer's toolbox, making it quantitative and prescriptive, but preliminary indications are that it is a promising path to explore.

7. CONCLUSIONS

We have presented analyses of the job of the NTD and a computational model of the NTD performing that job. The computational model seems adequate for quantitative evaluation of the performance time of individual, routine cognitive tasks that are a part of the total task of the NTD. The discourse analysis provides information that can be incorporated into the model to produce fairly rich simulated communications, and can be used to reason qualitatively about the effects of computer support systems on the communication patterns. Although potentially useful as it stands, this model touches only the routine, baseline behavior of the NTD; it is still to be extended to include the critical aspects of situation assessment, orientation in anomalous situations, training and learning, and the interaction of computer support systems with these vital behaviors.

ACKNOWLEDGEMENTS

We wish to thank Frank Merlino in the NTD office at the Kennedy Space Center (KSC) for his help in understanding the NTD position, William Rock and Edward Hecker in the Advanced Projects Office at KSC for their support of this project, Aura Hanna (NASA-Ames), Felicia Ferko (CMU), and Sandy Esch (CMU) for their help in data analysis, Allen Newell at CMU for his technical insights, and Mike Shafto in the Aerospace Human Factors Research Division at the NASA-Ames Research Center for his many contributions, both technical and administrative.

REFERENCES

Card, S. K., Moran, T. P., & Newell, A. (1983) *The psychology of human-computer interaction.* Lawrence Erlbaum, Associates, Hillsdale, NJ.

Card, S. K., Robertson, G. G., and Mackinlay, J. D. (1991) "The Information Visualizer, and Information Workspace" to appear in Proceedings of *CHI '91*(New Orleans, April 29-May 3, 1991) ACM, New York.

Carley, K., Kjaer-Hansen, J., Prietula, M., & Newell, A. (1990) "Plural-Soar: A Prolegomenon on artificial agents and organizational behavior" to appear in M. Masuch and G. Massimo (eds.) *Distrbuted Intelligence: Applications in Human Organizations*, Elsevier.

Clark, H. H. (1985) "Language use and language users" in G. Lindzey & E. Aronson (eds.) *The Handbook of Social Psychology* 3rd edition, New York: Knopf.

Egan, D. E. (1991) private communication.

Gray, W. D., John, B. E., Stuart, R., Lawrence, D., Atwood. M. E. (1990) GOMS meets the phone company: Analytic modelling applied to real-world problems. *Proceedings of Intertact '90 Third IFP Conference on Human-Computer Interaction.* Cambridge, England.

John, B. E. (1990) Extensions of GOMS analyses to expert performance requiring perception of dynamic visual and auditory information. In proceedings of *CHI, 1990* (Seattle, Washington, April 30-May 4, 1990) ACM, New York, 107-115.

Laird, J. E., Newell, A., & Rosenblom, P. S. (1987) Soar: An architecture for general intelligence. *Artificial Intelligence, 33,* 1-64.

Lewis, R. (1991) private communication.

Lewis, R. L., Huffman, S. B., John, B. E., Laird, J. E., Lehman, J. F., Newell, A., Rosenblom, P. S., Simon, T., & Tessler, S. G. "Soar as a Unified Theory of Cognition: Spring 1990. in the *Proceedings of the Twelfth Annual Conference of the Cognitive Science Society,* July, 1990.

Newell, A. (1990) *Unified theories of cognition.* Cambridge, Mass: Harvard University Press.

Newell, A. & Simon, H. (1972) *Human Problem Solving.* Prentice Hall.

Olson, J. R. & Olson, G. M. (1990) The growth of cognitive modeling in human computer interaction since GOMS. *Human Computer Interaction, 5,* 221-266.

Young, R. M. (1991) private communication.

Appendix 1. Transcript used for the preliminary discourse analysis

Utterance	Speaker	Utterance	Message	Episode
1	CGLS	Countdown clock will resume on my mark	1	1
2		3		
3		2		
4		1		
5		mark		
6	CGLS	T-20 minutes and counting	1	
7	NTD	Step 907 verified complete	2	2
8	NTD	Houston Flight, NTD	3	3
9		212 we got a requested weather briefing at this time		
10	FLT	We will not need that one we'll we'll have an update at T-9.	4	
11	NTD	Copy	5	
12	OTC	All personnel after transition to OPS 101 discontinue all LDB PMU reads for remainder of countdown	6	4
13	DPS	OTC DPS	7	5
14	OTC	Go DPS	8	
15	DPS	PASS OPS transition complete DPS ready for BFS transition to OPS 101	9	
16	OTC	Copy	10	
17	OTC	GNC pickup of 913	11	6
18	GNC	913 complete	12	
19	OTC	CDR take BFS to OPS 101 per your checklist	13	7
20	CDR	CDR in work	14	
21	NTD	STM NTD 212	15	8
22	STM	STM	16	
23	NTD	Step 963 terminate the video track and a closeout crew	17	
24	NTD	SRO, NTD	18	9
25	SRO	NTD SRO	19	
26		go ahead		
27	NTD	alright ah step 964 KSC area clear for launch	20	
28	SRO	Roger copy thank you	21	

29	NTD	STM, NTD deactivate the pad OIS	22	10
30	STM	STM copy	23	
31	OTC	CEPP verify step 916 please?	24	11
32	CDR	OTC, CDR ah BFS has been ah	25	12
33		up and ah no unexpected ah		
34		fault messages		
35	CVFS	NTD, CVFS	26	13
36	NTD	Go ahead, CVFS	27	
37	CVFS	Ready for BFS uplink	28	
38	NTD	I copy	29	
39	NTD	Houston Flight, NTD	30	14
40		Perform BFS preflight uplink loading		
41	FLT	In work	31	
42	OTC	PLT	32	15
43		configure pass and BFS horizontal sit displays per your checklist		
44	PLT	PLT In work	33	
45	COFC	OTC, COFC 212	34	16
46	OTC	Go ahead OFC	35	
47	COFC	Ah yeah steps 0921	36	
48		22 23 24 and 25 are complete		
49	OTC	Copy	37	
50	COFC	And flight control driver crew position check is up	38	
51		ready for pressurization		
52	OTC	Copy	39	
53	NTD	SRO, NTD	40	17
54		212		
55	SRO	NTD SRO go ahead sir	41	
56	NTD	Verify if 70 minute jimsphere has normal track	42	
57	SRO	yes, sir	43	
58		it has normal track		
59	NTD	copy	44	
60	FLT	NTD, Flight 212	45	18
61	NTD	Go ahead flight	46	
62	FLT	Pre-flight uplink loading complete	47	

63	NTD	I copy..ah..	48	
64		CVFS, you copy?	49	19
65	CVFS	CVFS copies, thank you	50	
66	NTD	OK	51	
67	STM	NTD STM	52	20
68	NTD	Go ahead	53	
69	STM	981 complete	54	
70	NTD	Copy that	55	
71	OOS	(mumbled: OOS) to launch	56	21
72	NTD	Go double S	57	
73	OOS	Ah steps 944 through 949 complete	58	
74	NTD	Copy	59	
75	PLT	OTC, PLT Horizontal sit config is complete	60	22
76	OTC	OK,	61	
77		Configure OMS interconnect per your checklist		
78		PLT		
79	PLT	in work	62	
80	FCP	OTC, CFCP	63	23
81	OTC	Go ahead FCP	64	
82	FCP	I can give you step 966.	65	
83		Fuel cell purges are complete and we're ready for fuel cell load adjust		
84	OTC	Copy	66	
85	FLT	NTD Flight 212	67	24
86	NTD	Go ahead, flight	68	
87	FLT	Today ah the IMU misalignment correction is not required	69	
88	NTD	Ah you're a little low, Flight	70	
89		Uh, you're reporting I- IMU misalignment not required		
90	FLT	That's affirm	71	
91	NTD	OK, copy that	72	
92	CVFS	OTC, CVFS	73	25
93	OTC	Go VFS	74	
94	CVFS	Yes sir, T-20 minute GPC dump is complete	75	
95	OTC	Copy	76	
96	NTD	All stations the countdown clock will hold at T-9 minutes for three minutes	77	26

97	NTD	Flight NTD 212	78	27
98	FLT	Houston flight go ahead	79	
99	NTD	We going to have to update the launch poly again?	80	
100	FLT	Negative	81	
101	NTD	Copy, thank you	82	
102	LPS	NTD, LPS	83	28
103	NTD	Go ahead LPS	84	
104	LPS	971 complete 972 not performed	85	
105	NTD	Copy	86	
106	EPD	OTC, EPD	87	29
107	OTC	Go EPD	88	
108	EPD	Yeah, fuel cell load share adjust complete	89	
109	OTC	OK copy	90	
110	OTC	We're standing by for completion on OMS interconnect	91	30
111	PLT	OTC PLT	92	31
112	OTC	PLT OTC go ahead	93	
113	NTD	T-9 minutes and holding	94	32
114	OTC	PLT OTC I did not copy your last	95	33
115	PLT	Roger OTC the OMS interconnect is complete	96	
116	OTC	Copy that	97	
117	OTC	We're ready to perform MPS helium reconfiguration	98	34
118		(pause almost 12 seconds) PLT you copy?	99	
119	PLT	PLT that's in work and how do you read me?	100	
120	OTC	A little low John	101	
121	PLT	OK how about now OTC	102	
122	OTC	That's good, PLT	103	
123	PLT	OTC, PLT	104	35
124		MPS helium reconfig is complete		
125	NTD	Flight, NTD waiting on the RTLS altimeter setting and runway	105	36
126	OTC	PLT report RCS quantities forward left and right oxidizer and fuel	106	37
127	PLT	OK..ah....	107	
128		The..ah..		
129		forward oxidizer 68,		
130		fuel 67,		

131		left oxidizer 99,		
132		left fuel 99,		
133		right oxidizer 99,		
134		right fuel 100		
135	OTC	Copy	108	
136	FLT	NTD, Flight 212	109	38
137	NTD	Go ahead flight	110	
138	FLT	OK we'd like to tell the crew update the RTLS runway	111	
139		and update to ah Zaragosa		
140	NTD	OK, ah, CDR stand by to copy	112	39
141		Flight, CISL, JSRP, NTD activate recorders please	113	
142	ISL	ISL copies	114	
143	FLT	Flight copies	115	
144	JSRP	JSRP copies	116	
145	FLT	Atlantis Houston	117	40
146	CDR	Go ahead Houston	118	
147	FLT	Got a couple of updates for you looks like ah for RTLS we'll want to use runway 15.	119	
148		Our upper level winds are headwinds are 33 and at set down margins they're just too low,		
149		so we'll be using 15		
150	CDR	OK we copy ah runway 15	120	
151	FLT	And ah just for your info KSC 15 if we should use it would be 2000 feet nominal	121	41
152		touchdown with a nominal endpoint		
153		and about 40% speed brakes (???)		
154		Right now both Zaragoza and Marone in the tower, they're ??? to tell us that vis is unrestricted		
155		Ah and Zaragosa		
156		at 30 will be looking at about a 1600 ft touchdown at 195		
157		with ah..31% speed breaks		
158	CDR	OK ah we copy, and	122	42
159		ah...		
160		any word on the TACAN that lost (???) the knob in the weather brief(???)		
161	FLT	Oh yeah, I forgot to tell you that	123	
162		ah..		
163		it is up and ah working, it has not been flight tested, however		
164	CDR	OK we copy	124	

Appendix 2. Speech Acts in OIS Communications

KEY TO THE FORMAT OF THIS APPENDIX

Speech Act - FORM = ALL CAPITALS indicates the contents of columns in the OMI,
"Quotes" indicate specific words that are commonly used
[square brackets] indicate an optional part of the speech act
| indicates an "or" relation with the adjacent term
PRECONDITIONS are what the speaker believes to be true in the world prior to the speech act
[a list of the speaker's beliefs follows]
POSTCONDITIONS are what is true in the world after the speech act
[a list of the truths follows]

Summons - FORM = RESP, CMD, [Channel]
PRECONDITIONS
1. the summoned party is passively listening
2. the summoned party will actively listen to the communication after hearing the summons
3. the summoned party can answer the summons
4. the summoned party will answer the summons when the summoning party stops talking
5. the summoned party can know who the summoning party is from the content of the summons
6. the summoning party knows who the summoned party is

POSTCONDITIONS
1. the summoning party is actively listening for an answer
2. the summoning party is expecting an answer now
3. the summoned party has had an opportunity to hear the summons
4. the summoned party has had an opportunity to know who the summoner is

Answer - FORM = RESP, ["Go" | "Go ahead"|] [CMD]
PRECONDITIONS
1. the summoned party has heard the summons
2. the summoned party knows who the summoning party is
3. the summoning party is expecting an answer now
4. the summoning party is actively listening for an answer

POSTCONDITIONS
1. the summoned party is actively listening
2. the summoned party knows who the summoning party is
3. the summoned party is waiting for further information from the summoning party
4. the summoning party has had an opportunity to hear the answer

Request -

FORM = assertive | directive

PRECONDITIONS

1. the requestor is at the correct OMI location
2. the requestor is authorized to make the request, as written in the OMI
3. the requestor knows who the requestee is
4. the requestee is the correct person to receive the request, as written in the OMI
5. the requestee is actively listening
6. the requestee can understand the request
7. the requestee can get to the correct OMI location via SEQ or DESCRIPTION
8. the requestee has the information, or the ability to get the information, needed to comply with the request
9. the requestee knows who the requestor is
10. the requestee will give the information to the requestor when it is available

POSTCONDITIONS

1. the requestor is actively listening
2. the requestor is expecting a compliance or promise now
3. the requestor wants the information now
4. the requestor will be satisfied with a promise to provide the information in the future
5. the requestee has had an opportunity to hear the request

Promise -

FORM = commissive

PRECONDITIONS

1. the requestee has heard the request
2. the requestee understands the request
2. the requestor is authorized to make the request, as written in the OMI
3. the requestee knows who the requestor is
4. the requestee is the correct person to receive the request, as written in the OMI
3. the requestee does not have the necessary information now
4. the requestee can get the necessary information later
5. the requestor is actively listening
6. the requestor is already at the request in the OMI
7. the requestor wants the information now
8. the requestor will be satisfied with a promise to provide the information later

POSTCONDITIONS

1. the requestee is committed to comply with the request in the future
2. the requestee is actively listening
3. the requestee expects a registration of the promise now
4. the requestor has had the opportunity to hear the promise

Registration - FORM = "Copy" | "In work" | "OK" | others

PRECONDITIONS

1. the partner is actively listening
2. the partner is expecting a registration
3. the registering party has heard the information
4. the registering party has understood the information
5. the registering party is at the step location in the OMI (or will go to it as needed)
6. the registering party is authorized to do the action implied by the information
6. the registering party is able to do the action implied by the information
   - for a promise, there is nothing to do at this time
   - for a compliance, this involves marking down the information in the OMI as appropriate
   - for a direction, this involves doing whatever was directed
   - for an assertion, this involves marking down the information in the OMI as appropriate
   - for a refusal, this involves marking down the information in the OMI as appropriate

POSTCONDITIONS

1. the registering party is committed to doing the action implied by the information
2. the partner has had the opportunity to hear the registration

Compliance - FORM = assertive

PRECONDITIONS

1. the requestee has heard the request
2. the requestee understands the request
2. the requestor is authorized to make the request, as written in the OMI
3. the requestee knows who the requestor is
4. the requestee is the correct person to receive the request, as written in the OMI
5. the requestee is at the correct location in the OMI
6. the requestee has the necessary information
7. the requestor is actively listening
8. the requestor is already at the request in the OMI
9. the requestor wants the information now

POSTCONDITIONS

1. the requested information was supplied
2. the requestee is actively listening
3. the requestee expects a registration of the compliance now
4. the requestor has had the opportunity to hear the compliance

Direction - FORM = directive (often exact words from the OMI)
PRECONDITIONS
1. the director is at the correct OMI location
2. the director is authorized to make the direction, as written in the OMI
3. the director knows who the directee is
4. the directee is the correct person to receive the direction, as written in the OMI
5. the directee is actively listening
6. the directee can understand the request
7. the directee can get to the correct OMI location via SEQ or DESCRIPTION
8. the directee is capable of performing the direction
9. the directee knows who the director is
POSTCONDITIONS
1. the director is actively listening
2. the director is expecting a registration now
3. the directee has had an opportunity to hear the direction

Assertion - FORM = assertive
PRECONDITIONS
1. the partner is actively listening
2. the partner can locate the step in the OMI via SEQ or DESCRIPTION
3. the asserter has the authority to make the assertion, as written in the OMI
4. the asserter knows who the partner is
5. the partner is the proper person to receive the assertion, as written in the OMI
6. the partner knows who the asserter is
POSTCONDITIONS
1. the asserter is actively listening
2. the asserter is expecting a registration now
3. the partner has had an opportunity to hear the assertion

Offer - FORM = assertive, directive
PRECONDITIONS
1. the offeror is at the correct OMI location
2. the offeror is authorized to make the offer, as written in the OMI
3. the offeror knows who the offeree is
4. the offeree is the correct person to receive the offer, as written in the OMI
5. the offeree is actively listening
6. the offeree can understand the offer
7. the offeree can get to the correct OMI location via SEQ or DESCRIPTION
8. the offeree knows who the offeror is
9. the offerer has the information offered at the time of the offer
10. the offerer is willing to give the information to the partner at the time of the offer if the partner accepts
11. the offerer is willing for the offeree to refuse (otherwise it would be a direction, not an offer)
POST CONDITIONS
1. the offeror is actively listening
2. the offeror is expecting an acceptance or refusal now
3. the offeree has had an opportunity to hear the offer

Acceptance - FORM = assertive, directive

PRECONDITIONS

1. the offeree has heard the offer
2. the offeree understands the offer
3. the offeror is authorized to make the offer, as written in the OMI
4. the offeree knows who the offeror is
5. the offeree is the correct person to receive the offer, as written in the OMI
6. the offeree does not have the necessary information now
7. the offeree wants the information now
8. the offeree has found the correct step in the OMI
9. the offerer will give the information now after the acceptance is performed

POSTCONDITIONS

1. the offeree is actively listening
2. the offeree expects the information offered now
3. the offeror has had the opportunity to hear the acceptance

Refusal - FORM = assertive

PRECONDITIONS

1. the offeree has heard the offer
2. the offeree understands the offer
3. the offeror is authorized to make the offer, as written in the OMI
4. the offeree knows who the offeror is
5. the offeree is the correct person to receive the offer, as written in the OMI
6. the offeree does not want the information now
7. the offeree has found the correct step in the OMI

POSTCONDITIONS

1. the offeree is actively listening
2. the offeree expects a registration of the refusal now
3. the offeror has had the opportunity to hear the refusal