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THESIS

L4151

DEVELOPMENT OF A MODEL WHICH PROVIDES A TOTAL SYSTEM APPROACH TO INTEGRATING VOICE RECOGNITION AND SPEECH SYNTHESIS INTO THE COCKPIT OF US NAVY AIRCRAFT

by

Margaret A. Lee

September 1988

Thesis Advisor G. R. Poock

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Pilot workload saturation in the cockpit of the US Navy Aircraft has become a serious concern. Literature, studies, and flight tests indicate that utilizing a voice interactive system for certain cockpit tasks can reduce this workload by decreasing the time required to perform the task.

This being the case, the problem which remains is one of deciding which tasks to convert. Therefore, a model has been developed which provides the designer with a total systems approach for use in deciding what combination of tasks, which if converted for performance by the voice interactive system, will result in the greatest workload reduction without overloading the pilot's voice channels.

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Development of a Model Which Provides a Total System Approach to Integrating Voice Recognition and Speech Synthesis Into the Cockpit of US Navy Aircraft

by

Margaret A. Lee
Lieutenant, United States Navy
B.A., Mississippi State University, 1975

Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

Pilot workload saturation in the cockpit of US Navy Aircraft has become a serious concern. Literature, studies, and flight tests indicate that utilizing a voice interactive system for certain cockpit tasks can reduce this workload by decreasing the time required to perform the task.

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I. INTRODUCTION

A. BACKGROUND

A major problem for the U S Navy flight program is pilot workload saturation in the cockpit. This creates a situation in which there is no reserve to deal with unforeseen contingencies and no room to add other needed tasks. The Naval Air Development Center (NADC) located at Warminster, Pennsylvania, is particularly interested in finding a solution which can be implemented without creating a corresponding degradation in the performance of the individual aircraft's mission [Interview with Warner, 1987].

Research in the area of dual-task performance indicates four ways of tackling this problem [Wickens,1981].

1. Training pilots to perform multiple tasks more efficiently.
2. The use of criteria which select those individuals with more proficient time-sharing skills in the recruitment of pilots.
3. Designing the cockpits so that the pilot will only be requested to concurrently perform tasks which are more efficiently shared.
4. Design the placement of controls and displays in the cockpit to allow for greatest time-sharing efficiency.

The design of the cockpit has been studied extensively so that it is doubtful that any further large reductions in workload can be achieved in that area. Pilot selection could not be based solely on time-sharing abilities even if techniques for accurate measurement of this ability were

currently available. Pilot selection must be based on many more important criteria. Also, since pilots already receive extensive training it is doubtful that any significant increases in efficiency can be achieved by providing additional training. Therefore, attention is being focused on the third alternative of trying to ensure that tasks, which a pilot must perform concurrently, are compatible for the purpose of efficient time-sharing.

Recent studies indicate that the use of voice recognition/synthesis in an aircraft cockpit may provide the best means of achieving the compatibility of tasks which will achieve the desired goal of workload reduction.

B. LITERATURE SEARCH

A large volume of material dealing with operator workload has been generated in recent years. This interest in operator workload is most likely the result of the existence of jobs which require multiple tasks to be performed in a very complex environment. An excellent example of such a job is the piloting of a U. S. Navy aircraft.

Literature generated in the area of human performance covers all aspects of time-sharing, display design, single and multiple tasking, attention resources, etc. Because of this proliferation of research it is necessary to limit the

review of this material to that of attention resources and time-sharing. These two areas provide the theoretical basis for pursuing the use of voice recognition/synthesis in an aircraft cockpit as a means to reduce pilot workload.

1. Attention as a Limited Resource

In 1967 Moray published a paper which highlighted the quantitative aspects of attention. He asserted that attention should be thought of as having a limited capacity in much the same way that a given computer is limited in how much data it can process. Additionally, he stated that this capacity could be divided into various amounts to be assigned to tasks on the basis of difficulty and demand. Particularly beneficial was the flexibility and ability to share these resources that was highlighted in his treatment of the subject. [Wickens,1984:pp. 292-293]

2. Kahneman Model

The Kahneman model is important because it was the first attempt to predict performance based on the limited capacity/resource theory. However, his model still dealt with attention as having a single source capacity and could not account for instances in which more difficult secondary tasks interfered less with the primary task than other less difficult tasks. This seemed to indicate that the theory of a single resource was possibly too simplistic. [Wickens,1984 and Wickens,1987]

3. Multiple-Resource Theory

The single resource theory of the Kahneman Model was valuable in asserting the idea of attention as a limited capacity resource. However, it failed to explain differences from predicted results which occurred when certain tasks were combined. [Wickens, 1984]

In an attempt to resolve these apparent discrepancies, Wickens developed a Multiple-Resource model which combined not only the theory of attention as a resource but also the theories of attention as structural in nature [Wickens,1981, Wickens,undated, Wickens,1988 and Wickens, 1984].

Building on research by individuals such as Pachella (1974), Kinsbourne and Hicks (1978), Harris, Owens and North (1978) and others [Wickens,undated]; Wickens designed a three dimensional model (Figure 1) which describes attention along the dimensions of (1) stages of processing, (2) cerebral hemisphere of operation and (3) modalities of processing (encoding and response).

Stages of processing include the processes of encoding, memory & transformations, and responding. The idea of different sequentially ordered stages of processing has achieved a certain level of acceptance and even though it cannot be inferred that independent resources are used,

some research in dual tasking seems to indicate it could be. [Wickens, undated]

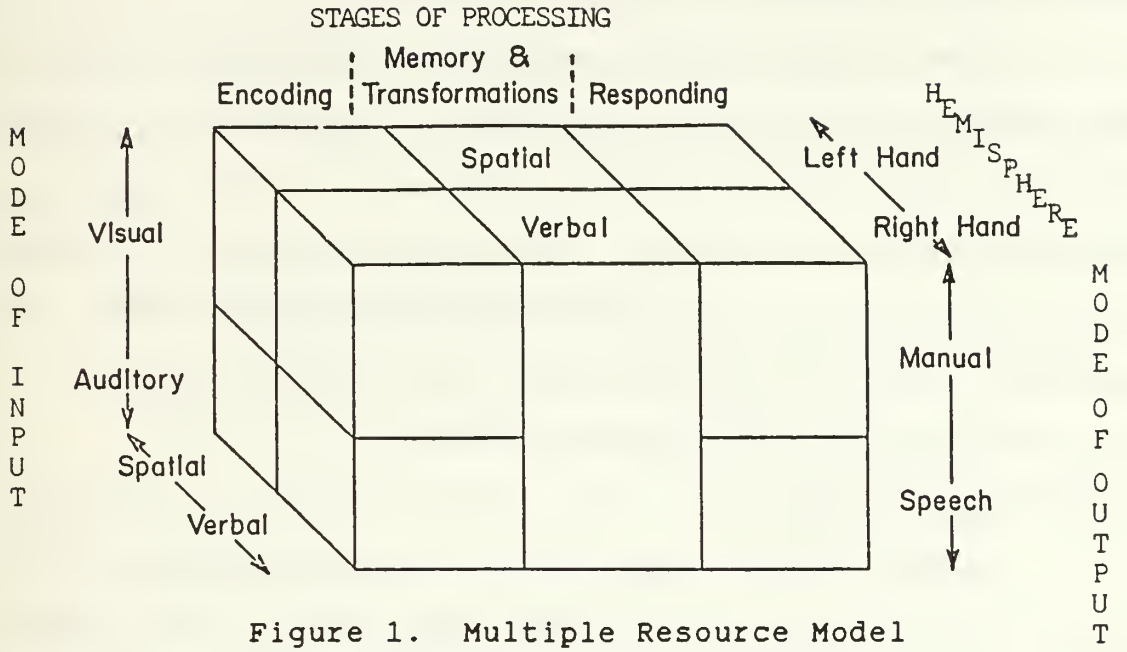

Figure 1. Multiple Resource Model (Adapted from Wickens (undated))

The research done in the area of separate cerebral hemispheres of operation argues strongly that the two cerebral hemispheres act as separate resource reservoirs. In particular, spatial tasks along with left hand controls are handled by the right hemisphere of the brain whereas verbal tasks and right hand controls are handled in the left. Since a slight additional amount of time is needed in order for the brain to send messages between the hemispheres of the brain, it is considered advantageous in certain circumstances to keep processing of a single task confined to one hemisphere. However, in other situations it is

beneficial to use both hemispheres since competition for the same resources can cause a slower response than that resulting from hemisphere crossover time.

Some of the clearest measurements have been along the dimension of different modalities of processing in which auditory versus visual encoding, and manual versus vocal responses have been studied. Sandry demonstrated the effect of these modalities in her experiment conducted on the F-18 simulator located at the Naval Air Test Center, Patuxent River, Maryland in 1981 [Sandry,1982].

4. Sandry Study

In her testing, Sandry paired verbal and spatial tasks[1] with the continuous primary spatial task of flying an aircraft. By comparing reaction times of different input/output modality pairs, inferences concerning expected performance could be made. In general, she found that the time required to complete a verbal task could be reduced by changing to a modality combination which utilized voice recognition and/or synthesis while such a combination resulted in degraded spatial task performance.

---

[1]Wickens defines verbal tasks as "Tasks for which words, language, or logical operations are natural mediators ...". Spatial tasks are defined as "... almost any task that requires moving, positioning, or orienting objects in space, or performing other analog transformations,..." [Wickens,1987:p. 16].

Sandry's study was useful in two ways. First, she directs attention immediately to those tasks which will be most benefited by voice implementation. Second, because the data was gathered on the Navy's F-18 simulator, it can be used for an initial cut in projecting possible reaction time savings.

C. DEPARTMENT OF DEFENSE STUDIES

1. Air Force B-52 Bomber Study [North and Lea,1982]

This study represents the armed forces' first attempt to identify cockpit tasks which would be benefited most by conversion from visual/manual input/output modalities to audio/vocal modalities. The approach developed by Honeywell dealt with cockpit tasks on an individual mission basis. A filtering system was then developed which screened and prioritized candidate tasks using a series of objective and subjective criteria.

2. Navy F/A-18 Study [Mountford, North, Metz, and Graffunder,1982]

The Navy study, which was also conducted by Honeywell, had three objectives. They were to (1) perform a literature review, (2) develop task selection procedures, and (3) study `dialogue' issues. Of primary interest to this thesis is the second objective of task selection. The resulting procedures refined those developed as part of the B-52 study.

These two studies performed by Honeywell, although valuable, are weak in two areas. First, determination of technological feasibility for a particular candidate task for voice implementation is done with a weighting factor. It would be much more straight forward to use a go/no-go decision process for this. When Warner at NADC attempted to use the proposed filtering process, tasks which were not technologically feasible were not successfully screened out [Interview With Warner,1987].

Secondly, the filtering process designed during these studies chooses and prioritizes candidate tasks on an individual basis with only a limited ability to judge the interference effect when multiple tasks are converted to voice. There is no attempt to determine the most advantageous combination of voice tasks.

D. DEPARTMENT OF DEFENSE FLIGHT TESTS

The military services, in spite of some valid reservations, have displayed a continued interest in voice synthesis/recognition as a possible solution for the saturated workload situation present in the aircraft cockpit. As a result, flight tests have been performed, the results of which are discussed below.

1. F/A-18A Flight Tests [Loikith and Hall,1986]

The purpose of these flight tests was to determine the feasibility and pilot utility of voice synthesis/recognition. Results of the tests indicated that voice implementation of cockpit tasks was feasible and could be useful provided that technical problems with the particular voice system tested could be corrected. The Lear Siegler, Inc; Voice Control Interactive Device was used for these tests.

2. AFTI/F-16 Flight Tests [Williamson,undated]

Using the Texas Instrument Voice Interactive System the Air Force obtained impressive results. The following excerpt from the "Discussion" portion of the report reveals how well this testing went.

> The test pilots found it safer and more convenient to use voice instead of traversing the awkward menu logic of multifunction keyboards and displays. The ability to request information verbally and receive a verbal response has also received universal praise from the pilots.

This report also highlights the fact that development of a method for selecting the most promising tasks for conversion to voice is necessary.

3. JOH-58C Helicopter Flight Tests [Szerszynski,1987]

The Army also experienced favorable results using voice in the JOH-58C helicopter. One of the sub-tests

conducted was a simulated single pilot mission[2] during which the pilot had to simultaneously control flight tasks, radio control, and visual search . Their assessment of the test results was that "The voice controlled avionics system is, based on the data, the avionics control system of choice when the workload is high".

These tests all demonstrate the ability of voice synthesis/recognition as a means to reduce pilot workload thereby increasing efficiency and safety. The last two tests in particular confirm the fact that the necessary voice technology is currently in existence.

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[2]The phrase "simulated single pilot mission" was used since a second pilot was along for safety reasons.

II. MODEL

A. OVERVIEW

The primary goal of this thesis is to combine previous research and DOD studies into a single model which will provide the design engineer with guidelines and procedures for a total systems approach to implementing voice recognition/synthesis in the cockpit. Wickens states the goal of this model best.

> A major goal of predictive performance models is to help determine the most effective design before a system is configured. Such models are not likely to be 100% reliable. However, they may prevent the designer from developing prototypes that will be clearly non-optimal, and will also enable the designer to identify a parameter space that is most worthy of experimental investigation. [Wickens,1988]

Likewise, this model will provide the most beneficial starting place for design and testing but cannot be expected to provide "the answer". Variances between aircraft and ever changing missions preclude any other approach.

This model draws extensively from the methods developed in the Honeywell studies [North and Lea,1982 and Mountford, North, Metz and Graffunder,1982] which use a total systems approach in deciding what systems to activate by voice. The performance data generated by Sandry (1982) provides the data for use in projecting expected workload savings. The product of this model will allow the design engineer to

begin with a first cut will maximize workload savings while avoiding overloading the pilot on the voice interactive side.

To aid in the future refinement of this model, individual modules will be used to separate distinct portions. Detailed descriptions of these modules follow.

B. MODEL DESCRIPTION

1. Module One

a. Task Analysis:

This portion of the model was developed by Honeywell [North and Lea,1982:pp. 8-14 and Mountford, North, Metz and Graffunder,1982:pp. 6-18] as part of two studies performed for NADC.

(1) Mission Scenario: According to the Honeywell studies, the first step in analyzing an aircraft cockpit regarding the value of implementing voice synthesis/recognition is to develop a mission scenario. This scenario should be a general narrative which accurately describes the mission under consideration.

Honeywell deals with mission scenarios individually, taking each mission separately and running it through the entire procedure. In this model a broader look is taken. All of the major missions of the particular aircraft under study should be developed and evaluated

together to provide an analysis which produces recommendations for voice implementation based on the aircraft as a total system.

In choosing the missions to evaluate, consideration should be given to high workload missions although it is important to include all major missions. Infrequently flown missions should not be considered unless unusually critical since they will unduly affect the findings of the evaluation process.

(2) Task Narrative: The second step advocated by Honeywell, is the development of a task narrative which provides a detailed verbal description of each task of the mission. A task narrative should be developed for each mission scenario. An example of a task narrative is contained in the F-18 Honeywell study [North and Lea,1982:p. 9] and has been provided as Table 1. The tasks should be listed in the order in which they occur during the flight.

(3) Time-based Activity Log: The next step in the Honeywell procedure is to use the Task Narrative to "...categorize each activity into its human information processing channels--vocal, visual, auditory, and manual." [Mountford, North, Metz, and Graffunder,1982:p. 10]. Also an index should be included which indicates the difficulty in distance and location the pilot experiences in reaching for the manual control. Those tasks for which the pilot

does not reach would be assigned a value of zero and increase in incremental steps of one up to the most difficult. This reach index is a useful measure when combined with other information in deciding the best candidates for speech synthesis/recognition. In Honeywell's F-18 study example the highest value was a three. Figure 2 provides an example of how this index could be assigned to an aircraft cockpit.

Table 1. TASK NARRATIVE
(Adapted From North and Lea (1982))

Pilot Tasks	Copilot Tasks	Additional Aircrew Tasks
Calls for preparation for contact checklist.	Reads preparation for contact checklist.	RN--Calls range to tanker in 1 NM increments. Calls range at 3 . . . 2 NM.
1. Establish radio contact		
	2. Check air conditioning system.	
		N--3. Set rendezvous radar to standby.
	4. Turn anticollision lights off.	
	5. Turn navigation lights to flash.	
6. Disengage autopilot.	6. Set slipway and airplane light switches to full bright.	
7. Set airbrake lever to position 1.	7. Open slipway doors and verify ready lights on.	
	8. Determine tanker position on FLIR sensor.	RN--8. Determine tanker position on FLIR sensor.
9. Select FLIR video.		
	10. Set air refueling switch to air refuel.	

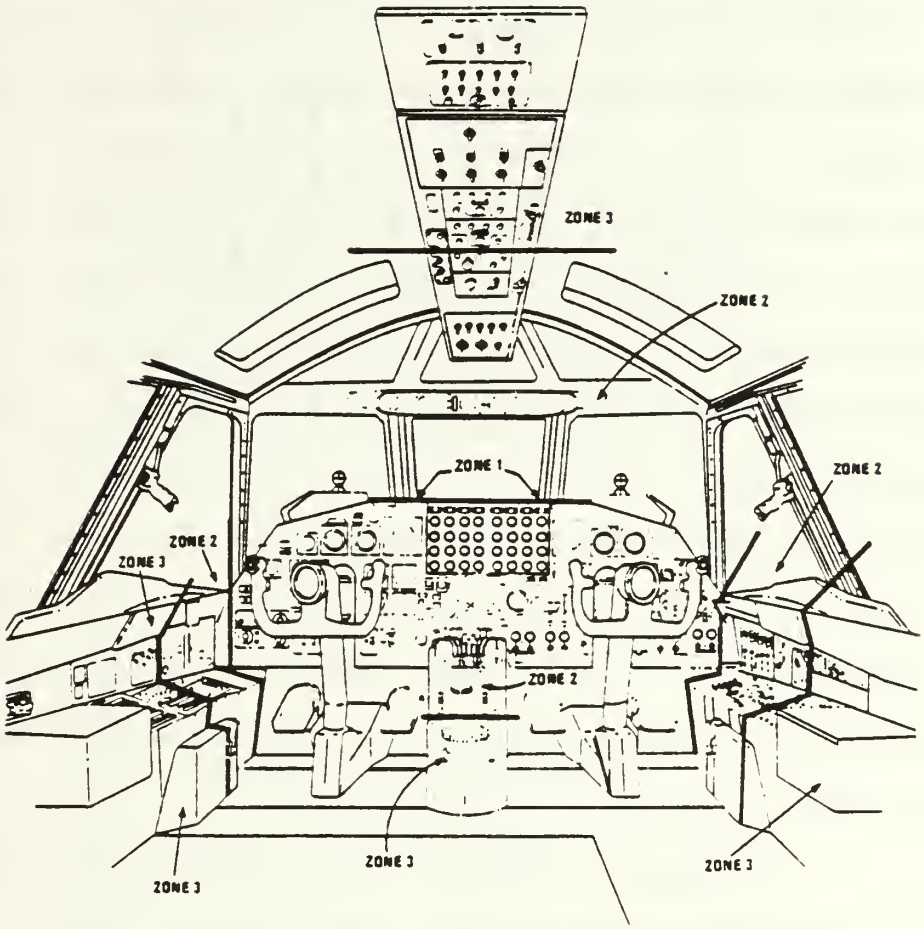

Figure 2. Anthropometric Zones
(Adapted From North and Lea(1982))

An example of the Time-based Activity Log is included as Table 2 [Mountford, North, Metz, and Graffunder,1982:p. 11]. Immediately obvious in this sample is the fact that many of the tasks show input or output modes of "N" (not applicable). This is not appropriate. Each task can have both input and output modes specifically identified. For the case where a "not applicable" entry appears appropriate the following guidelines should be employed. If the task is prompted by a checklist it should be considered to have a visual input mode. If it is a memory item, then it should be listed as an audio input mode because this most closely identifies the information processing channel (hemisphere) used. In the case of output modes the vocal mode should be identified. This follows from the fact that if no obvious manual action occurs then the information processing channels activated must be the same as those used for a vocal response.

(4) Activity Chart: This chart is the graphic form of time-based activity log. See Figure 3 below [Mountford, North, Metz, and Graffunder,1982:p. 13]. These charts are particularly important to the subsequent screening of proposed tasks for voice implementation since they provide quick information on which tasks are performed in conjunction with the flight task thereby creating a dual

Table 2. TIME-BASED ACTIVITY LOG
(Adapted from Mountford, North, Metz, and Graffunder (1982))

Time	Input	Output	Verification	Anthropometry	Inf. Retrieval	Task Brief
000	A	V	N	0	N	COPIES CALL FROM GROUND CONTROL
002	A	V	N	0	N	COPY GROUND FOR FINAL WEATHER CHECK
002	A	V	N	0	N	COPIES TAKEOFF BRIEFING
005	V	N	N	0	Y	REVIEWS TAKEOFF PROCEDURE AND THE SID
006	N	V	N	0	Y	REVIEWS TAKEOFF CHECKLIST
015	N	M	N	1	N	RELEASES BRAKES
016	A	M	V	2	N	SET ENGINE STALL PREVENTION SWITCH TO CLIMATIC
016	N	V	N	0	N	CALLS "70 KNOTS, NOW"
016	N	V	N	0	N	CALLS "COMMITTED"
016	N	M	V	1	N	APPLIES WHEEL BRAKES
016	N	V	N	0	N	"FLAPS UP"
017	N	M	V	3	N	SELECTS FLIGHT DIRECTOR FOR HEADING
018	N	V	N	0	N	"WATER-OUT EPR"
021	N	V	A	0	Y	CALLS AFTER TAKEOFF-CLIMB CHECKLIST
023	N	M	V	3	N	SELECTS FLIGHT DIRECTOR FOR NAV GUIDANCE
024	N	V	M	3	N	ENGAGES AUTOPILOT TO CAPTURE DESIRED HEADING
025	N	M	V	1	N	RESETS ALTIMETERS
035	N	M	V	2	N	SET THRUST GATE
035	N	M	V	2	N	SET STARTER SWITCHES TO CLIMATIC

tasking situation. This information will be necessary during the optimization portion of this model.

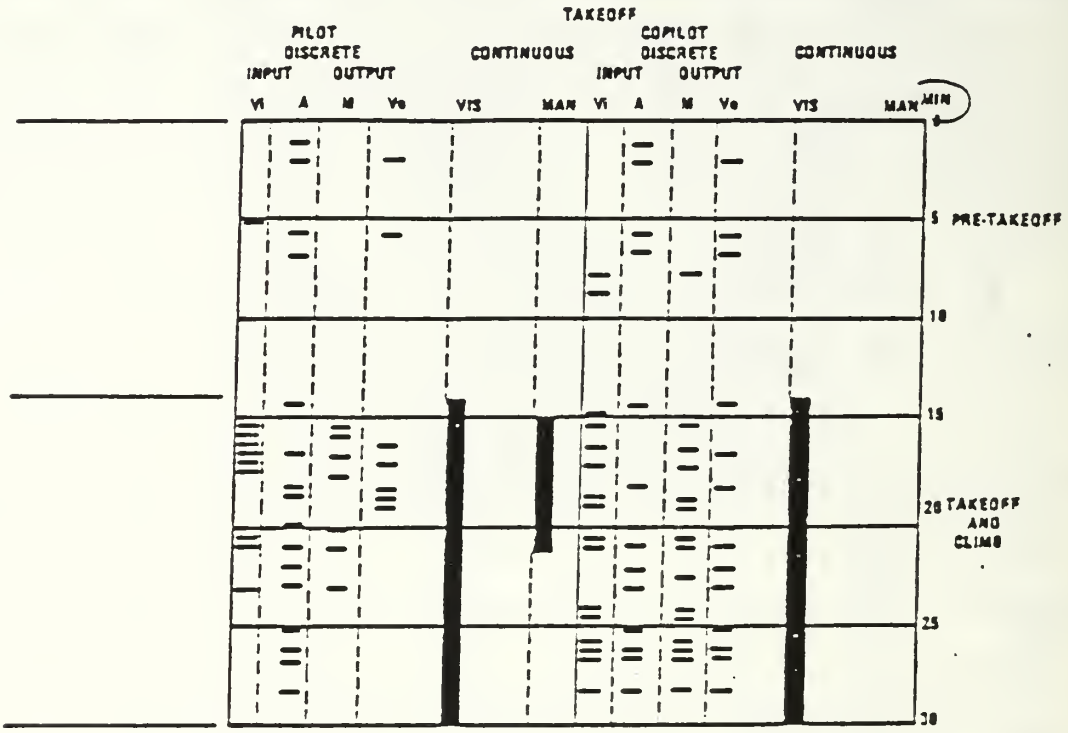

Figure 3. Activity Chart
(Adapted From Mountford, North, Metz, and Graffunder (1982)

b. Development of Speech I/O Candidate Task List:

After producing the task analysis for all pertinent scenarios, an initial list of potential candidates for conversion to voice should be compiled. Each task should be evaluated by the following series of filters. These filters provide the first gross look at a given task to judge its suitability for voice.

(1) Verbal Task Filter: This first filter asks whether or not the task can be classified as one using the verbal information processing channels (see Footnote 1). If the answer is yes, it will continue through the filters which follow. If no, it will be rejected immediately. Currently, only verbal tasks benefit from conversion to voice synthesis/recognition.

(2) Speech Recognition Filter: This filter is used to decide whether a task would be a good candidate for speech recognition. The questions for this filter were developed in the Honeywell B-52 study, further refined in the Honeywell F-18 study and are provided in flowchart form as Figure 4 [Mountford, North, Metz, and Graffunder,1982:p. 20].

One additional question has been added to this filter. The first question asks if the task is currently accomplished with a by pilot speech. If the answer is yes, it will be immediately rejected since it already uses voice output. If no, it will continue through this filter.

The question concerning the number of times the task is performed during the mission has been transferred to its own filter so that this it can be more efficiently handled.

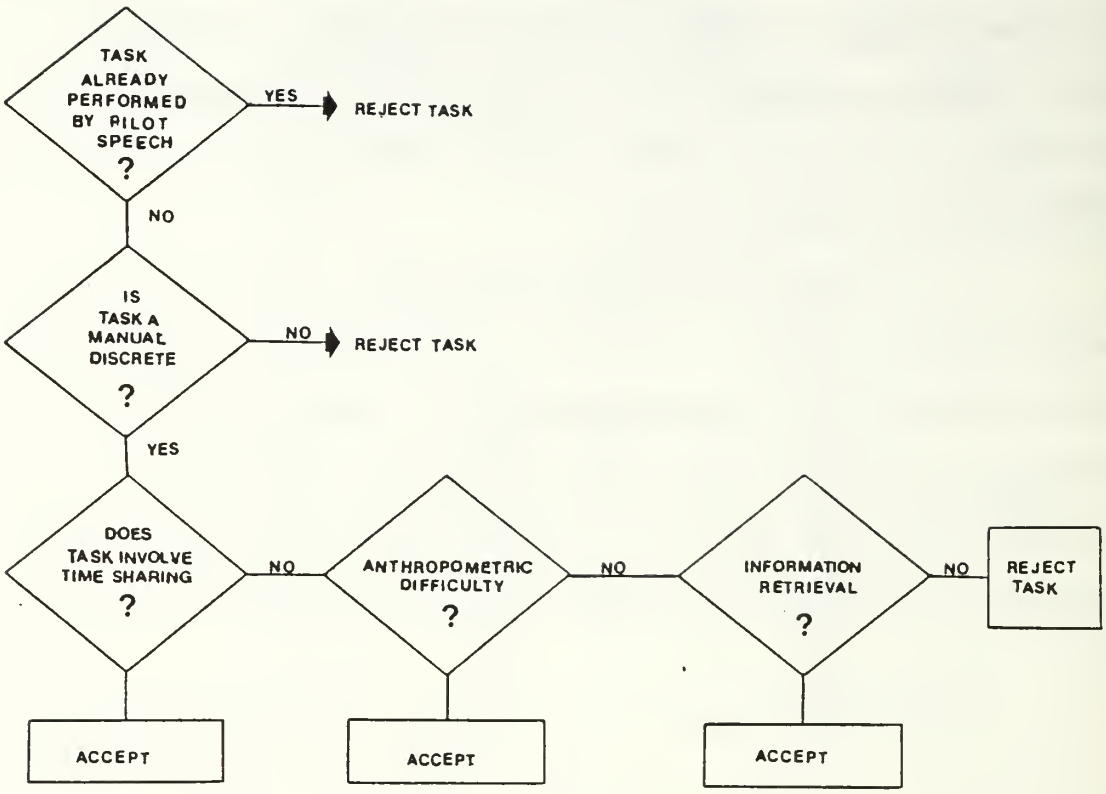

Figure 4. Speech Recognition Filter (Adapted From Mountford, North, Metz, and Graffunder (1982) and Modified By Author)

(3) Speech Generation(Synthesis) Filter: This filter is used to decide whether a task would be a good candidate for speech synthesis. A flowchart for the following questions is provided in the Honeywell B-52 study

[North and Lea,1982:p. 21]. It should be noted that question one was added to the filter by this author.

1. Is the task currently handled by speech input to the pilot? If yes, reject task. If no, continue to evaluate.
2. Can information be transmitted to pilot/co-pilot as a short phrase? If no, reject task. If yes, continue to evaluate.
3. Does it occur during visual time-sharing? If yes, accept task. If no, continue to evaluate.
4. Can it be used as an information display that currently does not occur in the central anthropometric visual zone? If yes, accept task. If no, continue to evaluate.
5. Can it be used together with speech recognition in an interactive dialogue format? If yes, accept. If no, reject.

(4) Technical Feasibility: This filter is used to decide whether a task can be implemented as part of the voice system from a technical standpoint (e.g., if a task is using equipment not controlled through the multi-plexer (mux), the voice system cannot access it and the task will be dropped from the candidate task list). This is a question which must have a yes or no answer from an engineering standpoint. Therefore, each task which was accepted by either the Speech Recognition Filter and/or the Speech Generation Filter should be evaluated technically.

This procedure differs from the Honeywell studies which address this issue from the standpoint of a feasibility scale which is judged to provide little additional information and only serves to obscure the analysis by adding an additional factor. In fact, the use

of such a scale could lead to accepting a task which cannot be implemented.

(5) Repetition Filter: At this point, the tasks which have successfully passed through the previous filters should be grouped according to equipment used, input/output mode, number of steps to complete, and anthropometry index. This is done so that the frequency with which the same actions are taken can be judged[3]. Once this grouping has been compiled, the decision maker must decide how many times a task must be repeated before it becomes advantageous to consider conversion to voice modes.

Once this decision has been made, only those tasks which occur with the proper frequency will be placed on the Candidate Task List.

(6) Candidate Task List: Once a task has been accepted as a candidate for voice synthesis and/or recognition it should be placed on the Candidate Task List which is the output for this module. Along with each task the current input/output modes and the anthropometry index should be listed. An example of the procedure described in this module is included in the Appendix.

---

[3]This handling of task repetition differs from the Honeywell studies in that instead of being part of the Speech Recognition Filter, it is handled as a separate filter. The reason for this change is that grouping the tasks as described above prior to asking this question simplifies the process considerably when this procedure is put into practice.

2. Module Two--Pilot Input

Pilot involvement in the task selection process is considered essential by NADC [Interview With Warner, 1987]. Pilots possess a wealth of knowledge and experience, which if properly used, will greatly enhance this selection process. In addition, the involvement of the pilots should result in greater acceptance of this new technology.

Both of the Honeywell Studies [North and Lea,1982 and Mountford, North, Metz, and Graffunder, 1982] address the assignment of a pilot utility rating to those tasks which are contained in the Candidate Task List produced in module one above.

In the Honeywell F/A-18 study [Mountford, North, Metz, and Graffunder, 1982], it was suggested that pilots be given a questionnaire which contains questions requiring checks in blocks which are scaled on an ordinal basis from one (never useful) to six (always very useful). The following example is taken directly from that study.

Example: "Descent Checklist"

	1	2	3	4	5	6	
Never Useful	_____	_____	_____	_____	_____	_____	Always very Useful
			Sometimes Useful				

Responses should be compiled to show both how many pilots selected a given rating and the average rating. This

allows the decision maker to choose either the average or that rating that was picked most often (the mode) as the combined utility rating to be used in the optimization module. The following example illustrates this process.

Example: "Descent Checklist"

	1	2	3	4	5	6		
Never Useful	____	1	4	8	15*	12	Always very Useful	Average 4.83
				Sometimes Useful				

*Indicates mode

In this example, there is very little difference between the average and the mode even though these two figures could vary greatly.

In evaluating the feedback provided by this questionnaire, strong consideration should be given to deleting any task from the candidate list which receives ratings which fall primarily in the 1 and 2 range. If not completely eliminated, these tasks could still be selected in the optimization module if other weighting factors are high enough. In most cases it would be counter productive to provide a voice task which the pilots have already indicated would not be useful.

The output of this module is a list of candidate tasks along with the assigned pilot utility rating for each.

3. Module Three--Performance Specifications

The goal of this portion of the model is to establish performance specifications which can be used in Module Four to maximize workload reduction (reaction time savings).

These performance specifications must include both the single and dual task conditions. The reason for inclusion of the single task condition is that the mission's activity chart produced in module one includes time frames in which the pilot/co-pilot is not engaged with the flight task, thus becoming a single task situation.

In establishing performance specifications, it is first necessary to determine whether the numbers should reflect the worst case, best case or expected (average) case. This must be decided on an individual case basis.

One method for establishing these specifications is demonstrated using the data from the Sandry study [Sandry,1982]. As previously mentioned, reaction times and root mean squared error rates were gathered through use of the Navy's F-18 simulator. The pilots used were from the local flying club and had an average of nine years experience[1].

[1]Since F-18 pilots are used for data gathering efforts only on advanced high level projects, the experience level of the pilots used by Sandry was appropriate.

For the purposes of this model, workload is defined by reaction time. This means that the reduction of the amount of time necessary to complete a task directly translates into a reduction of workload (reaction time savings) for the pilot/co-pilot.

Prior to using the data collected by Sandry, its validity for the purpose of establishing performance specifications was evaluated. A linear regression model was used for this analysis. Using the Statgraphics Package by STSC, regressions were run for single verbal task reaction times, single spatial task reaction times, dual verbal task reaction times, dual spatial task reaction times, dual verbal task root mean square values, and dual spatial task root mean square values. The results were as follows:

1. Residuals indicated that the linear regression model was appropriate for the reaction times but not the best choice for root mean square error rates (Figure 5). However, since it is only necessary to judge general trends for the error rate (which were adequately identified by the linear regression), no additional models were evaluated.
2. Verbal tasks but not spatial tasks were benefited by conversion to voice input and/or output modes. Therefore, no performance specifications will be developed for spatial tasks.
3. Error rate declines when voice input and/or output modes are used (Figure 6).
4. In a single task condition, a variance is found among the subjects, which although is statistically significant, disappears in the dual task condition.
5. The independence of the variables was confirmed.

In establishing the performance specifications for this demonstration, mean reaction times were used.

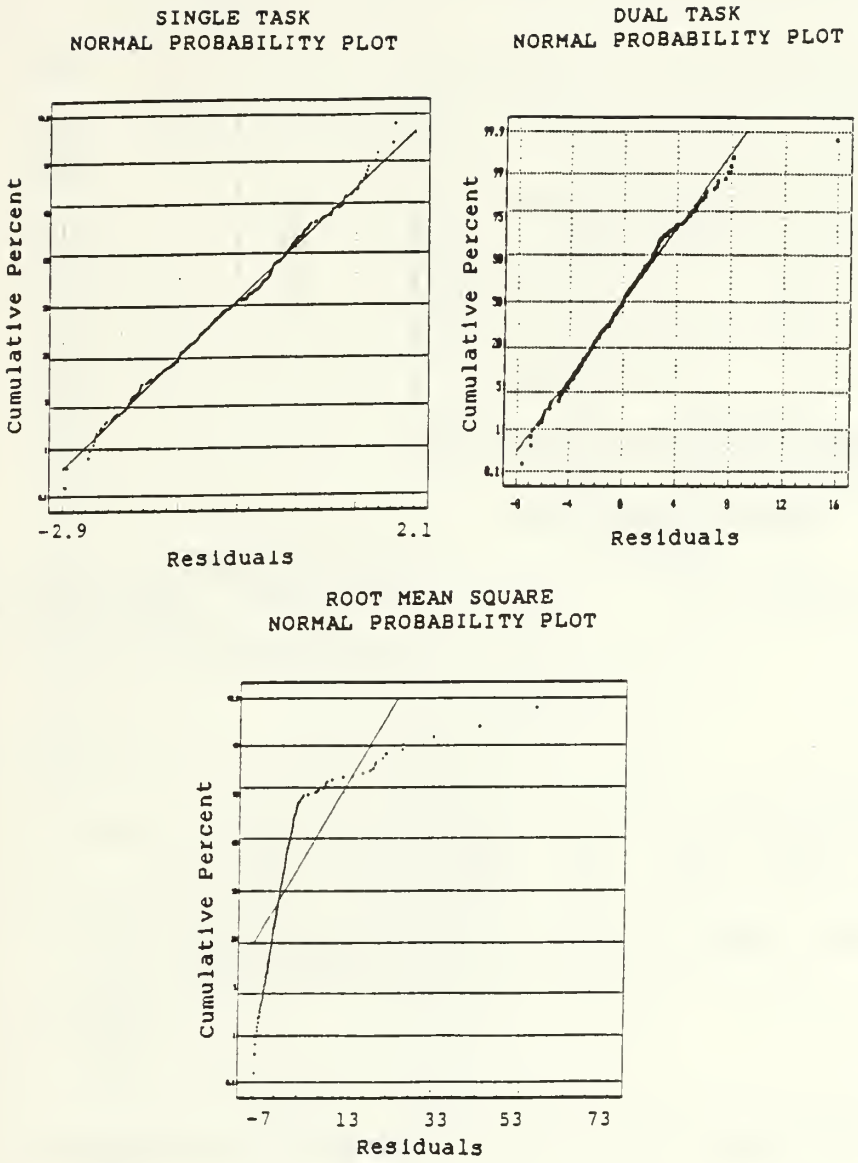

Figure 5. Normal Probability Plots [in secs]

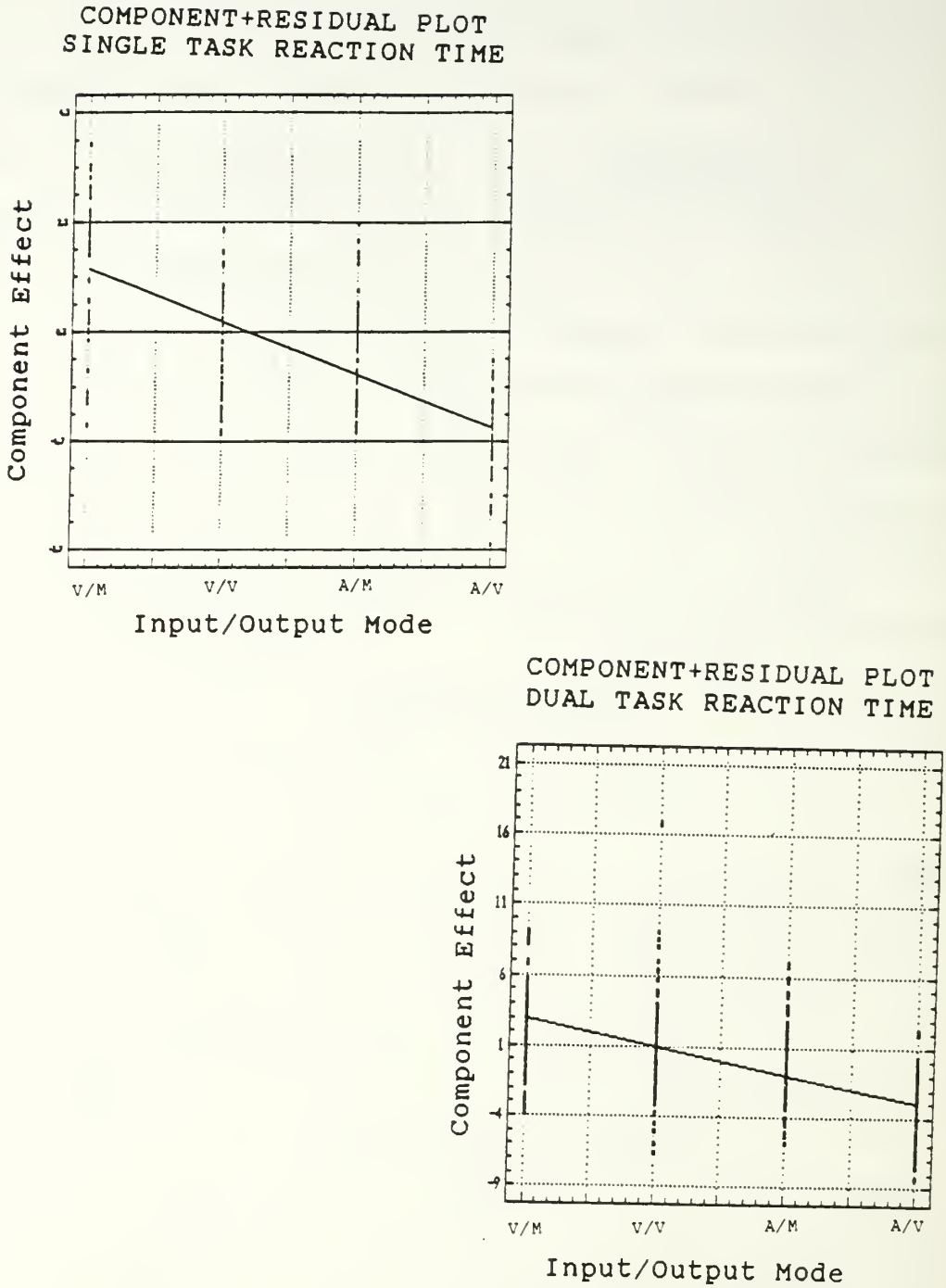

Figure 6. Component+Residual Plots [in secs]

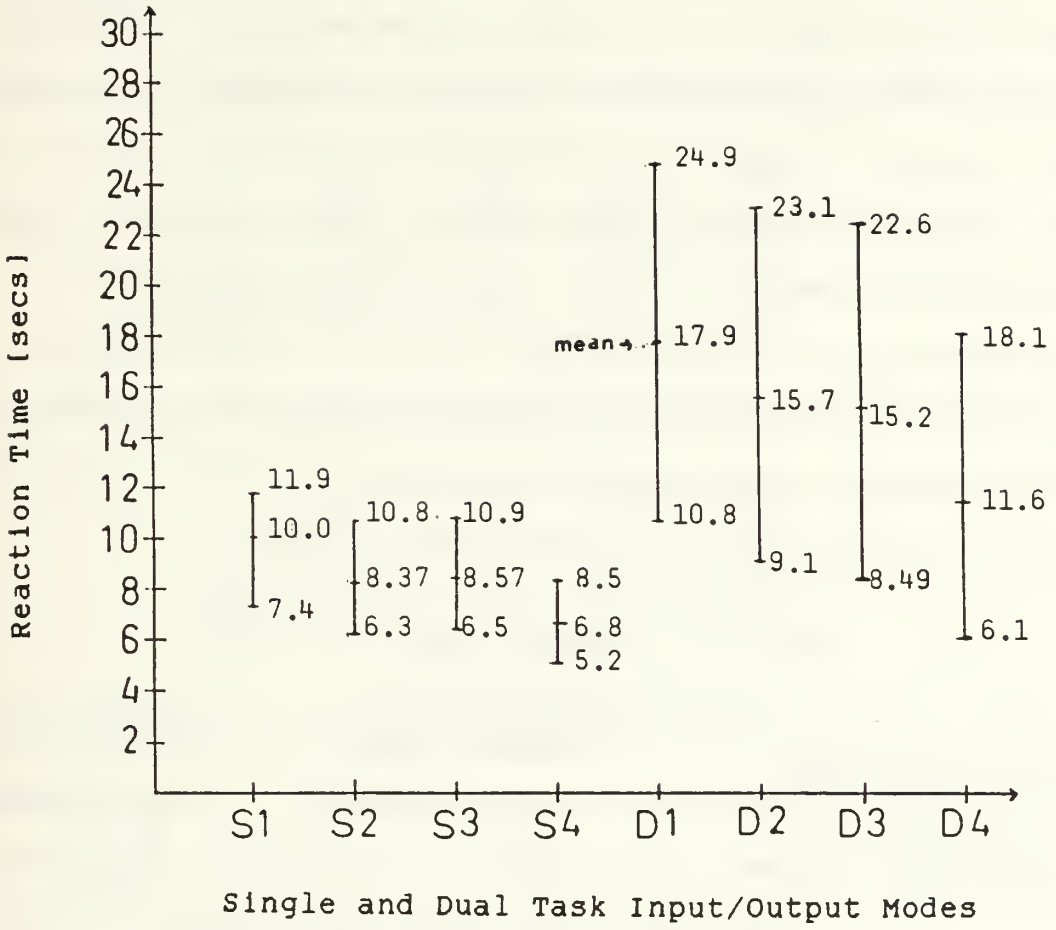

Figure 7. Plot of Reaction Time Variances[5]

[5]The letters S and D were used to distinguish between single and dual tasks, respectively. The numbers shown with these letters identify the input/output modes as follows:

1 = Visual/Manual
2 = Visual/Vocal
3 = Audio/Manual
4 = Audio/Vocal

Figure 7 shows the spread of the reaction times by input/output mode and by single/dual task condition. The trend present in the intervals shown is consistent with that shown by the means. Therefore, the means can be used for ease of computation purposes without distorting the outcome. The increase in the variance between the single and dual task conditions is explained by the resource capacity theory discussed in Chapter I. The variance present, while a consideration, does not prohibit the use of the average in establishing performance standards. Table 3 below provides the performance specifications expected for tasks in each of the four combinations of input/output modes.

Table 3. AVERAGE REACTION TIMES

Input/Output Mode	Single Task Reaction Times	Dual Task Reaction Times
Visual/Manual (V/M)	10.03 [secs]	17.91 [secs]
Visual/Vocal (V/V)	8.37	15.69
Audio/Manual (A/M)	8.57	15.24
Audio/Vocal (A/V)	6.8	11.59

Tables 4 and 5 provide the expected difference in reaction time which will occur if the input/output modality is changed.

Table 4. SINGLE TASK REACTION TIME SAVINGS (seconds)

		To			
		V/M	V/V	A/M	A/V
From	V/M	0	1.66	1.46	3.23
	V/V	-1.66	0	-0.20	1.57
	A/M	-1.46	0.20	0	1.77
	A/V	-3.23	-1.57	-1.77	0

Table 5. DUAL TASK REACTION TIME SAVINGS (seconds)

	To			
	V/M	V/V	A/M	A/V
V/M	0	2.22	3.67	6.32
V/V	-2.22	0	0.45	4.10
A/M	-3.67	-0.45	0	6.32
A/V	-6.32	-4.10	-6.32	0

The potential for reducing reaction time is found by locating the row which lists the input/output mode combination currently in use and combining this with the column indicating the candidate input/output mode.

In many cases it will not be possible to pull the numbers from these tables and immediately use them. It is first necessary to relate the task at hand to those performed in the Sandry study. The most straight forward way to accomplish this is to consider the number of steps necessary to perform the task in question. The Sandry tasks required four steps for completion. Therefore, the reaction

time for the task under consideration can be obtained by multiplying the tabled reaction time by the ratio calculated by dividing the number of steps necessary to complete the current task by four.

Tables 3, 4, and 5 represent the type of output expected from this module.

4. Module 4--Optimization

This portion of the model represents the heart of the total systems approach to implementation of voice synthesis/recognition in the cockpit. The goal of this module is to select that combination of candidate tasks with associated input/output modes which will provide the largest reduction in workload without overloading the voice channels used by the voice input/output modes.

Linear programming is proposed as the preferred method for accomplishing this objective. This method was developed as a means of dealing with situations containing a large number of variables with associated constraints. As stated by the Operations Analysis Group (1984),

> Problems of allocation arise whenever there are a number of activities to be performed but limitations on either the amount of resources or the manner in which they may be allocated prevents accomplishment of each separate activity in the most effective way conceivable...a powerful technique that has been developed to solve such problems is called mathematical programming. When the problem can be formulated within a mathematical framework in such a way that it becomes one of maximizing or minimizing a linear expression subject to certain linear constraints, the technique is known as linear programming.

Likewise, this is an allocation problem and it can be formulated within the "mathematical framework" of a linear function with linear constraints. Such a mathematical formulation follows.

$$\text{Maximize} \sum_i \sum_j \sum_k \sum_l T_{ijkl} X_{ijkl} \qquad (2\text{-}1)$$

such that

$$\sum_i \sum_j \sum_k \sum_l R_{ijkl} <= C_j \qquad (2\text{-}2)$$

$$\sum_k X_{ijkl} <= 1 \qquad (2\text{-}3)$$

$$X_{ijkl} = X_{ijk2} = \ldots = X_{ijkn} \qquad (2\text{-}4)$$

where

i = Candidate Task
j = Mission
k = Input/Output Mode
l = Type of Task (single or dual condition)
T_{ijkl} = Utility Value[6] Of Task i, Mission j, Input/Output Mode k, and Type of Task l
X_{ijkl} = The Variable of Choice
R_{ijkl} = Reaction Time[7] For Task i, Mission j, Input/Output Mode k, and Type of Task l
C_j = Total Time (in seconds) of Additional Time Allowed For Voice Modes
n = Number of Missions Under Consideration

The objective equation in (2-1) maximizes the total reaction time savings for all of the missions under consideration. The constraint equation (2-2) restricts the amount of time which can be added to the voice information processing channels during a given mission so that the pilot will not

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[6] The utility value is the weighted combination of reaction time savings, pilot utility and anthropometry index. The importance of each element is dependent upon the judgement of the decision maker. One possible weighting scheme is demonstrated in the Appendix.

[7] This figure is obtained from Tables 4 and 5 as appropriate.

become overloaded in that area. This value is at the discretion of the decision maker. Constraint equation (2-3) limits the selection of the input/output mode to only one for each task. Lastly, constraint equation (2-4) insures that the same combination of tasks will be selected for each mission. This constraint is deleted when the missions do not contain identical tasks. When this occurs it will be necessary to evaluate the missions separately to establish the proper mix of tasks. However, in general, the same tasks will be present in every mission.

Any good linear programming package will be able to solve the above maximization problem, thereby supplying the system designer with the best initial combination of tasks. This combination of tasks will represent the largest workload savings possible while not overloading the pilots voice interactive channels. The LINDO (Linear, INteractive, Discrete Optimizer) software package by LINDO, Inc is used in the Appendix to solve an example problem.

C. MODEL SUMMARY

This model has intentionally been designed to be general in nature so that it is easily applied to any aircraft cockpit. The procedures described are specific enough to guide the system designer while retaining the flexibility necessary to address the needs of the individual aircraft.

In summary, this model consists of a series of questions which evaluate the potential of all tasks performed during all of the aircraft's missions. Those tasks which are considered as good candidates for conversion to voice synthesis/recognition are then rated by the pilots for usefulness resulting in a pilot utility index for each. The tasks are then evaluated by an optimization program using the performance specifications contained in Module Three to determine what combination of tasks will provide the greatest reduction in pilot workload without overloading the voice channels.

III. FUTURE STUDY

A. FURTHER DEVELOPMENT OF MODEL'S INDIVIDUAL MODULES

As stated in the overview of the model, individual modules representing distinct portions of the process have been used in order to facilitate the refinement process for this model.

Module One is fairly well complete but the processing of this portion would be greatly enhanced through use of automation. A computer program (possibly in Fortran) could be designed which would ask the appropriate filter questions and then generate the Candidate Task List as the final output.

Module Two requires pilot input and could also be greatly enhanced through the use of a computer program. The survey form could be automatically generated from the Candidate Task List prepared as part of module one.

Module Three could be improved in several ways. Although useful, better data on reaction times could be collected for use in establishing performance specifications by using actual F-18 pilots. Even if F-18 pilots could not be obtained, additional tasks could be tested on the simulator in hopes of obtaining more accurate reaction times. In the mean time, possibilities for a more reliable

method of converting the values in Tables 3, 4, and 5 could be explored.

Module Four will work well with any good optimization package but more study into different weighting schemes could prove to be valuable. Both modules three and four would benefit from being automated in a complete package with Modules One and Two.

B. TRAINING IMPLICATIONS

The training issue should be addressed for two reasons. Firstly, the Sandry study (1982) showed a significant reduction in reaction time for verbal tasks which were converted to voice synthesis/recognition input/output modes after only a small amount of training and practice. More dramatic results could occur with additional practice by the pilots. While pilots are practiced to the point of an automated response for visual and manual actions, this is not true for audio and vocal ones. Further, testing in this area could produce very favorable results which would lead to a greater recognition of voice interaction in the cockpit as a valuable asset for pilots.

Secondly, methods for instructing pilots in the use of a voice interactive system should be explored so as to facilitate the training process.

C. SYNTAX DEVELOPMENT

Selection of the words (syntax) to be used with the voice interactive system must be made carefully. These words must be meaningful to the pilot as well as distinguishable from each other by the recognition system. Words which sound too much alike would lead to a higher recognition error rate.

Pilot input into the selection process would not only result in a superior vocabulary but would lead to greater pilot acceptance.

D. SPATIAL TASKS

At this time only verbal tasks have been considered as candidates for voice synthesis/recognition. Literature in the field as well as the Sandry study (1982) have clearly demonstrated the fact that tasks processed by those information processing channels which are utilized by spacial tasks do not benefit by conversion to voice input/output modes.

However, the possibility does exist that some spatial tasks could be converted so that the verbal information processing channels would be used to perform the task. If this could be accomplished then conversion to voice modes could prove beneficial.

For example, a target tracking task could be designed such that the pilot could move a cursor to a designated grid by stating a letter-number combination rather than using a joystick to move the cursor to the same area.

Creative designing of cockpit tasks could greatly enhance the use of the voice interactive system.

APPENDIX

EXAMPLE OF MODEL PROCEDURE

The purpose of this example is to demonstrate step by step the procedures described in the model contained in Chapter II. The treatment of the included tasks has deviated from fact in some instances so that various aspects of the model could be more fully illustrated. The information for this example has been obtained from the Task Narratives contained in Appendix A of the Honeywell B-52 Bomber Study [North and Lea, 1982]. In this example the pilot's job will be analyzed.

A. MODULE ONE

Since the Mission Scenario and the Task Narrative are self-explanatory, this example will begin with the Time-based Activity Logs taken directly from the Honeywell study and contained here as Tables 6, 7, 8, and 9. As indicated by the logs, the mission segments are Takeoff, Lowlevel, Air Refueling, and Recovery. These segments are organized into two missions. Mission one consists of Takeoff, Air Refueling, and Recovery while mission two consists of Takeoff, Lowlevel, and Recovery.

Table 6. TAKEOFF ACTIVITY LOG
(Adapted From North and Lea (1982))

TAKEOFF (PILOT)

Time	Input	Output	Verification	Anthropometry	Inf. Retrieval	Task Brief
000	A	V	N	Ø	N	COPIES CALL FROM GROUND CONTROL
002	A	V	N	Ø	N	COPY GROUND FOR FINAL WEATHER CHECK
002	A	V	N	Ø	N	COPIES TAKEOFF BRIEFING
005	V	N	N	Ø	Y	REVIEWS TAKEOFF PROCEDURE AND THE SID
006	N	V	N	Ø	Y	REVIEWS TAKEOFF CHECKLIST
015	N	M	N	1	N	RELEASES BRAKES
016	A	M	V	2	N	SET ENGINE STALL PREVENTION SWITCH TO CLIMATIC
016	N	V	N	0	N	CALLS "70 KNOTS,,NOW"
016	N	V	N	Ø	N	CALLS "COMMITTED"
016	N	M	V	1	N	APPLIES WHEEL BRAKES
016	N	V	N	Ø	N	"FLAPS UP"
017	N	M	V	3	N	SELECTS FLIGHT DIRECTOR FOR HEADING
018	N	V	N	Ø	N	"WATER-OUT EPR"
021	N	V	A	Ø	Y	CALLS AFTER TAKEOFF-CLIMB CHECKLIST
023	N	M	V	3	N	SELECTS FLIGHT DIRECTOR FOR NAV GUIDANCE
024	N	V	M	3	N	ENGAGES AUTOPILOT TO CAPTURE DESIRED HEADING
025	N	M	V	1	N	RESETS ALTIMETERS
035	N	M	V	2	N	SET THRUST GATE
035	N	M	V	2	N	SET STARTER SWITCHES TO CLIMATIC

Table 7. LOW LEVEL ACTIVITY LOG
(Adapted From North and Lea (1982))

Time	Input	Output	Verification	Anthropometry	Inf. Retrieval	Task Brief
000	N	V	N	Ø	Y	"GET LL DESC CL"
002	V	M	V	1	N	TURN ON EVS TA VID
003	V	M	V	2	N	ANTI-ICING PANEL
003	V	M	V	2	N	CLEAR PLANE
003	V	M	V	1	N	RAD ALT TO 800 FT
004	V	M	V	1	N	SET ALTS
004	N	M	T	1	N	DUMP AP
010	V	M	V	3	N	AP TO LL
012	N	N	V	1	N	CHK ALTS
012	N	M	V	1	N	SET ALTS
020	V	N	V	1	N	CHECK GEAR, FLAPS UP
022	N	V	N	Ø	N	"GET TA CHCKLST UP"
023	V	M	V	3	N	SET ALT HOLD AP
024	N	V	N	1	N	CHK ALTS
025	N	V	A	Ø	N	"YOUR AIRPLANE"
026	V	N	V	1	N	COMPARE STAB MODES
027	N	M	T	3	N	SET STAB REF SEL.
	N	M	V	1	Y	FILL IN WORKSHEET
030	N	M	V	3	N	PROFILE SET
031	V	N	V	1	N	READ RAD ALT.
032	N	M	V	1	N	SET CL PLANE CAL VAL
033	N	M	V	1	N	SET ALTS
033	N	M	V	2	N	SET STAB REF SEL
034	V	M	V	3	Y	SET CL PLANE TO ALT
034	V	M	V	1	Y	SET RADALT CURSOR
036	N	V	N	Ø	N	"I HAVE THE AC"
037	N	V	N	Ø	N	RCVS BRUN HDG FM RN
042	V	N	N	Ø	N	RCVS DEF MAN CMDS EW
044	N	M	V	2	N	TURNS BOMB REL LITES

Table 8. AIR REFUEL ACTIVITY LOG
(Adapted From North and Lea (1982))

Time	Input	Output	Verification	Anthropometry	Inf. Retrieval	Task Brief
000	A	N	N	0	N	HEAR RNAV CALL RANGE
003	V	A	A	0	N	"LEVEL AT FL290"
004	A	N	N	0	N	RNAV CALL
004	N	V	N	0	N	"BEGIN YOUR TURN"
004	V	V	A	0	N	"VISUAL CONTACT"
006	N	V	N	0	Y	"GET PREP CNTCT CL"
006	N	V	A	0	N	"LOUD AND CLEAR"
007	N	M	V	3	N	DISENGAGE AP
007	N	M	T	1	N	AIR BK SET
007	N	M	V	1	N	SET EVS FLIR VIDEO
008	V	V	A	0	N	"SPEED 270, CLIMBING"
008	N	M	T	3	N	AP TO AR MODE
010	A	V	N	0	N	BOOM OPS RADIO CK
011	A	V	A	0	N	"CLEAR TO CONT"
011	V	N	N	2	N	WATCH AR LITES
012	A	V	A	0	N	"CONTACT VERIFIED"
017	A	V	A	0	N	"PROBLEMS IN FUEL"
027	A	V	A	0	N	"ROGER, FUEL RCVD"
027	A	V	A	0	N	"DISCONNECTED"
050	N	V	N	0	N	"FINAL CONNECT"
052	N	V	N	0	N	"BRKAWAY PRAC"
062	N	V	N	0	N	"BREAKAWAYS"
063	N	M	T	1	N	DUMP AP AR MODE
064	V	V	N	0	N	"CLEAR TANKER"
065	N	V	A	0	N	"GET POST REF CL"

Table 9. RECOVERY ACTIVITY LOG
(Adapted From North and Lea (1982))

Time	Input	Output	Verification	Anthropometry	Inf. Retrieval	Task Brief
002	N	V	N	ø	Y	CALL DESCENT CLIST
002	A	M	V	1	N	SET ALT
003	A	M	V	1	N	SET AIRBRAKES
003	A	V	A	ø	N	CALLS CASTLE APPROACH
004	A	N	V	1	N	VERIFY LANDING GEAR DOWN
004	N	V	N	ø	N	REQ COPILOT TO EXTEND FLAPS
018	N	M	T	1	N	DUMP AP
019	N	M	T	1	N	AIR BRAKES
019	N	V	N	ø	N	DRAG CHUTE
019	N	M	T	1	N	CHECK AND APPLY WHEEL BRAKES
020	N	V	N	1	N	CHECK ALL HYDRAULIC
020	N	V	N	1	N	CHECK CROSSWIND CRAB
020	N	M	V	2	N	CENTER RUDDER PEDALS
020	N	V	N	ø	1	CALL CHECKLIST
021	V	M	V	2	N	DISENGAGES YAW AND PITCH SAS SW
021	V	M	V	2	N	ZEROIZE MODE 4 AND TURN OFF IFF

Activity charts have not been prepared for this example but it should be noted that single and dual tasking has been considered during this procedure as appropriate.

The next step in the process is to screen each task listed on the Time-based Activity Logs for inclusion on the Candidate Task List. It was decided that a spreadsheet approach would best suit the procedure so Lotus 1-2-3 was chosen for this purpose. Tables 10 and 11 contain the spreadsheets prepared in the process of screening tasks included in missions one and two respectively. A step by step explanation of the process follows.

The first step was to determine if the task was verbal[8]. If the answer was affirmative, "YES" was placed in the appropriate column. If the answer was negative, the task was dropped from further consideration and "Reject" was entered. Once a task was rejected three dashes were placed in the remaining columns to indicate that this task was no longer under consideration for voice implementation.

Next, each task was processed through the Speech Recognition Filter. In response to the question of whether the output mode was currently vocal, either "NO" or "Reject" was entered. If a "NO" response was entered the question of whether the task was manual discrete was asked. The entries

[8] This term is defined in footnote 1.

Table 10. MODULE ONE SPREADSHEET--MISSION ONE

Task Brief	DATX Input	Output	Anthropometry	Inf. Retrieval	Verbal Task?	SPEECH RECOGNITION FILTER Output Mode Vocal?	Manual Discrete?	Time-Shared?	RD>0	Inf. Retrieved	Accept Task	SPEECH GENERATION FILTER Input Mode Audio?	Short Phrase?	Visual Timesharing?	RD>1	Interactive Dialogue?	Accept Task?	Technical Feasible?
Takeoff																		
COPIES CALL FROM GROUND CONTROL	M	V	0	M	YES	Reject	---	---	---	---		Reject	---	---	---	---		
COPY GROUND FOR FINAL WEATHER CHECK	M	V	0	M	YES	Reject	---	---	---	---		Reject	---	---	---	---		
COPIES TAKEOFF BRIEFING	M	V	0	M	YES	Reject	---	---	---	---		Reject	---	---	---	---		
REVIEWS TAKEOFF PROCEDURE AND THE S10	V	V	0	Y	YES	Reject	---	---	---	---		NO	Reject	---	---	---		
REVIEWS TAKEOFF CHECKLIST	V	V	0	Y	YES	Reject	---	---	---	---		NO	YES	NO	NO	Accept	M	YES
RELEASES BRAKES	V	X	1	M	YES	NO	YES	Accept	---	---	M	NO	YES	Accept	---	---	M	YES
SET ENGINE STALL PREVENTION SWITCH TO CLIMATIC	M	X	2	M	YES	NO	YES	Accept	---	---	X	Reject	---	---	---	---		Reject
CALLS "70 KNOTS, MON"	V	V	0	X	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	X	YES
CALLS "COMMITTED"	V	V	0	X	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	M	YES
APPLIES WHEEL BRAKES	V	M	1	M	Reject	---	---	---	---	---		---	---	---	---	---		
"FLAPS UP"	V	V	0	M	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	M	Reject
SELECTS FLIGHT DIRECTOR FOR HEADING	V	X	3	X	YES	NO	YES	Accept	---	---	M	NO	YES	Accept	---	---	X	YES
"WATER-OUT ERR"	V	V	0	M	YES	Reject	---	---	---	---	X	NO	YES	Accept	---	---	M	YES
CALLS AFTER TAKEOFF-CLIMB CHECKLIST	V	V	0	Y	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	X	YES
SELECTS FLIGHT DIRECTOR FOR NAV GUIDANCE	V	X	3	M	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	M	YES
ENGAGES AUTOPILOT TO CAPTURE DESIRED HEADING	V	V	3	M	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	X	YES
RESETS ALTIMETERS	V	X	1	M	YES	NO	YES	Accept	---	---	M	NO	YES	Accept	---	---	M	YES
SET THRUST GATE	V	X	2	M	YES	NO	YES	Accept	---	---	M	NO	YES	Accept	---	---	M	YES
SET STARTER SWITCHES TO CLIMATIC	V	M	2	M	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	M	Reject
Air Refueling																		
HEAD RNAV CALL RANGE	M	V	0	M	YES	Reject	---	---	---	---		Reject	---	---	---	---		
"LEVEL AT FL290"	V	V	0	M	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	M	YES
RNAV CALL	A	V	0	M	YES	Reject	---	---	---	---		Reject	---	---	---	---		
"BEGIN YOUR TURN"	V	V	0	M	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	X	YES
"VISUAL CONTACT"	V	V	0	M	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	X	YES
"SET PREP CHICT CL"	V	V	0	Y	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	X	YES
"LOUD AND CLEAR"	V	V	0	M	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	X	YES
DISENGAGE AP	V	V	3	M	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	M	YES
RIP BY SET	V	X	1	M	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	M	Reject
SET EVS FLIR VIDEO	V	X	1	M	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	M	YES
"SPEED 270, CLIMBING"	V	V	0	M	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	M	YES
AP TO AR MODE	V	X	3	M	YES	NO	YES	Accept	---	---	M	NO	YES	Accept	---	---	M	YES
BOOM OPS RADIO CK	M	V	0	M	YES	Reject	---	---	---	---		Reject	---	---	---	---		
"CLEAR TO CONT"	M	V	0	M	YES	Reject	---	---	---	---		Reject	---	---	---	---		
WATCH AR LITES	V	V	2	M	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	M	YES
"CONTACT VERIFIED"	X	V	0	M	YES	Reject	---	---	---	---		Reject	---	---	---	---		
"PROBLEMS IN FUEL"	X	V	0	M	YES	Reject	---	---	---	---		Reject	---	---	---	---		
"ROGER, FUEL RCVD"	X	V	0	M	YES	Reject	---	---	---	---		Reject	---	---	---	---		
"DISCONNECTED"	M	V	0	M	YES	Reject	---	---	---	---		Reject	---	---	---	---		
"FINAL CONNECT"	V	V	0	M	YES	Reject	---	---	---	---		Reject	---	---	---	---		
"BOOMAY PRAC"	V	V	0	M	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	M	YES
"BOOMAYS"	V	V	0	M	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	M	YES
DUMP AP AR MODE	V	V	0	M	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	M	YES
"CLEAR TANKER"	V	V	1	M	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	X	YES
"GET POST REF CL"	V	V	0	X	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	M	YES
				M	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	M	YES
Recovery																		
CALL DESCENT CLIST	V	V	0	Y	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	M	YES
SET ALT	M	M	1	M	YES	NO	YES	Accept	---	---	X	Reject	---	---	---	---		YES
SET WINDBRAKES	M	M	1	M	YES	NO	YES	Accept	---	---	X	Reject	---	---	---	---		YES
CALLS CASTLE APPROACH	M	V	0	M	YES	Reject	---	---	---	---		Reject	---	---	---	---		
VERIFY LANDING GEAR DOWN	M	V	1	M	YES	Reject	---	---	---	---		Reject	YES	Accept	---	---	M	YES
REQ COPILOT TO EXTEND FLAPS	V	V	0	M	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	M	Reject
DUMP AP	V	M	1	M	YES	NO	YES	Accept	---	---	M	NO	YES	Accept	---	---	M	YES
WIN BRAKES	V	M	1	M	Reject	---	---	---	---	---		---	---	---	---	---		
DRAG CHUTE	V	V	0	M	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	M	YES
CHECK AND APPLY WHEEL BRAKES	V	M	1	M	Reject	---	---	---	---	---		---	---	---	---	---		
CHECK ALL HYDRAULIC	V	V	1	M	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	X	YES
CHECK CROSSWIND CRAB	V	V	1	M	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	M	YES
CENTER RUDDER PEDALS	V	M	2	M	Reject	---	---	---	---	---		---	---	---	---	---		
CALL CHECKLIST	V	V	0	Y	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	M	YES
DISENGAGES YAW AND PITCH SAS SW	V	M	2	M	YES	NO	YES	Accept	---	---	X	Reject	---	---	---	---		Reject
ZEROIZE MODE 4 AND TURN OFF IFF	V	M	2	M	YES	NO	YES	Accept	---	---	X	Reject	---	---	---	---		Reject

Table 11. MODULE ONE SPREADSHEET--MISSION TWO

Task Brief	DATA Input	Output	Anthro-pometry	Inf. Retrieval	Verbal Task?	SPEECH RECOGNITION FILTER Output Mode Manual Vocal?	Discrete?	Time-Shared?	RD>0	Inf. Retrieved	Accept Task	SPEECH GENERATION FILTER Input Mode Short Audio?	Phrase?	Visual Timesharing?	RD>1	Interactive Dialogue?	Accept Task?	Technical Feasible?
Takeoff																		
COPIES CALL FROM GROUND CONTROL	M	V	0	N	YES	Reject	---	---	---	---		Reject	---	---	---	---		
COPY GROUND FOR FINAL WEATHER CHECK	M	V	0	N	YES	Reject	---	---	---	---		Reject	---	---	---	---		
COPIES TAKEOFF BRIEFING	M	V	0	N	YES	Reject	---	---	---	---		Reject	---	---	---	---		
REVIEWS TAKEOFF PROCEDURE AND THE SID	V	V	0	Y	YES	Reject	---	---	---	---		Reject	---	---	---	---		
REVIEWS TAKEOFF CHECKLIST	V	V	0	Y	YES	Reject	---	---	---	---		NO	Reject	NO	NO	Reject		
RELEASES BRAKES	V	M	1	N	YES	NO	YES	Accept	---	---		NO	YES	NO	NO	Accept	X	YES
SET ENGINE STALL PREVENTION SWITCH TO CLIMATIC	M	M	2	N	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	X	YES
CALLS "70 KNOTS, NOW"	V	V	0	N	YES	Reject	---	---	---	---	X	Reject	---	---	---	---		Reject
CALLS "COMMITTED"	V	V	0	N	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	X	YES
APPLIES WHEEL BRAKES	V	M	1	N	Reject	---	---	---	---	---		NO	YES	Accept	---	---	X	YES
"FLAPS UP"	V	V	0	N	YES	Reject	---	---	---	---		---	---	---	---	---		
SELECTS FLIGHT DIRECTOR FOR HEADING	V	M	9	N	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	X	Reject
"WATER-OUT EPR"	V	V	0	N	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	X	YES
CALLS AFTER TAKEOFF-CLIMB CHECKLIST	V	V	0	Y	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	X	YES
SELECTS FLIGHT DIRECTOR FOR NAV GUIDANCE	V	M	9	N	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	X	YES
ENGAGES AUTOPILOT TO CAPTURE DESIRED HEADING	V	V	9	N	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	X	YES
RESETS ALTIMETERS	V	M	1	N	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	X	YES
SET THRUST GATE	V	M	2	N	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	X	YES
SET STARTER SWITCHES TO CLIMATIC	V	M	2	N	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	X	Reject
Lowlevel																		
"SET LL DESC CL"	V	V	0	Y	YES	Reject	---	---	---	---								
TURN ON EVS TO VID	V	M	1	N	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	X	YES
ANTI-ICING PANEL	V	M	2	N	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	X	YES
CLEAR PLANE	V	M	2	N	Reject	---	---	---	---	---	X	NO	YES	Accept	---	---	X	Reject
RAD ALT TO 800 FT	V	M	1	N	YES	NO	YES	Accept	---	---		---	---	---	---	---		
SET ALTS	V	M	1	N	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	X	YES
DUMP AP	V	M	1	N	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	X	YES
AP TO LL	V	M	9	N	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	X	YES
CHK ALTS	V	V	1	N	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	X	YES
SET ALTS	V	M	1	N	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	X	YES
CHECK GEAR, FLAPS UP	V	V	1	N	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	X	YES
"SET TO CHECKLST UP"	V	V	0	N	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	X	YES
SET ALT HOLD AP	V	M	9	N	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	X	YES
CHK ALTS	V	V	1	N	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	X	YES
"YOUR AIRPLANE"	V	V	0	N	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	X	YES
COMPARE STAB MODES	V	V	1	N	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	X	YES
SET STAB REF SEL.	V	M	9	N	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	X	YES
FILL IN WORKSHEET	V	M	1	Y	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	X	YES
PROFILE SET	V	M	9	N	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	X	Reject
READ RAD ALT.	V	V	1	N	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	X	YES
SET CL PLANE CAL VAL	V	M	1	N	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	X	YES
SET ALTS	V	M	1	N	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	X	YES
SET STAB REF SEL	V	M	2	N	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	X	YES
SET CL PLANE TO ALT	V	M	9	Y	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	X	YES
SET PROFLT CURSOR	V	M	1	Y	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	X	YES
"I HAVE THE AC"	V	V	0	N	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	X	YES
RCVS BRUN MOG FR BN	V	V	0	N	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	X	YES
RCVS DEF MAN CMDS EN	V	V	0	N	YES	Reject	---	---	---	---		NO	Reject	---	---	---		
TRSANS BOMB REL LITES	V	V	2	N	YES	Reject	---	---	---	---		NO	Reject	---	---	---		
Recovery													YES	Accept	---	---	X	YES
CALL DESCENT CLIST	V	V	0	Y	YES	Reject	---	---	---	---								
SET ALT	M	M	1	N	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	X	YES
SET AIRBRAKES	M	M	1	N	YES	NO	YES	Accept	---	---	X	Reject	---	---	---	---		YES
CALLS CASTLE APPROACH	M	V	0	N	YES	Reject	---	---	---	---	X	Reject	---	---	---	---		YES
VERIFY LANDING GEAR DOWN	M	V	1	N	YES	Reject	---	---	---	---		Reject	---	---	---	---		YES
REQ COPILOT TO EXTEND FLAPS	V	V	0	N	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	X	YES
DUMP AP	V	M	1	N	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	X	Reject
AIR BRAKES	V	M	1	N	Reject	---	---	---	---	---		NO	YES	Accept	---	---	X	YES
DRAG CHUTE	V	M	0	N	YES	NO	YES	Accept	---	---	X	NO	YES	Accept	---	---	X	
CHECK AND APPLY WHEEL BRAKES	V	M	1	N	Reject	---	---	---	---	---		---	---	---	---	---		
CHECK ALL HYDRAULIC	V	V	1	N	YES	Reject	---	---	---	---		NO	YES	Accept	---	---	X	YES
CHECK CROSSWIND CRAB	V	V	1	N	YES	Reject	---	---	---	---		---	---	---	---	---		
CENTER RUDDER PEDALS	V	M	2	N	Reject	---	---	---	---	---		NO	YES	Accept	---	---	X	YES
CALL CHECKLIST	V	V	0	Y	YES	Reject	---	---	---	---		---	---	---	---	---	X	YES
DISENGAGES YAW AND PITCH SAS SW	V	M	2	N	YES	NO	YES	Accept	---	---	X	Reject	---	---	---	---		
ZEROIZE MODE 4 AND TURN OFF IFF	V	M	2	N	YES	NO	YES	Accept	---	---	X	Reject	---	---	---	---		Reject
																		Reject

were either "YES" or "Reject". If the answer was yes then the question was whether the task occurred during time-sharing. The entries were then either "Accept" or "NO". If no, then the task continued through the filter. Next, the question was asked about whether the Anthropometry Index was greater than zero. The entries were either "Accept" or "NO". For "NO" answers, the last question about whether the task resulted in information retrieval was asked. The entries were either "Accept" or "Reject".

In this example, no questions were necessary after the time-sharing question although all of the columns were included for completeness. Lastly, all of the accepted tasks were indicated as such by an "X" placed in the appropriate column following the Speech Recognition Filter.

Next, the Speech Generation Filter was applied. The questions in this filter were processed much the same as for the Speech Recognition Filter and should thus be self-explanatory.

The last question included on the spreadsheet dealt with the technical feasibility of the tasks accepted by the previous filters. If the task was accepted by either filter, it was screened for technical feasibility. If the task was not rejected it was listed on the Preliminary Candidate Task List shown in Table 12.

Table 12. PRELIMINARY TASK LIST

MISSION ONE--AIR REFUELING

Task Brief	Task* Number
Takeoff	
REVIEWS TAKEOFF CHECKLIST	1
RELEASES BRAKES	2
SET ENGINE STALL PREVENTION SWITCH TO CLIMATIC	3
CALLS "70 KNOTS, NOW"	4
CALLS "COMMITTED"	4
SELECTS FLIGHT DIRECTOR FOR HEADING	5
"WATER-OUT EPR"	4
CALLS AFTER TAKEOFF-CLIMB CHECKLIST	6
SELECTS FLIGHT DIRECTOR FOR NAV GUIDANCE	5
ENGAGES AUTOPILOT TO CAPTURE DESIRED HEADING	7
RESETS ALTIMETERS	8
SET THRUST GATE	9
Air Refueling	
"LEVEL AT FL290"	4
"BEGIN YOUR TURN"	4
"VISUAL CONTACT"	4
"GET PREP CNTCT CL"	4
"LOUD AND CLEAR"	4
DISENGAGE AP	10
SET EVS FLIR VIDEO	8
"SPEED 270, CLIMBING"	4
AP TO AR MODE	10
WATCH AR LITES	11
"FINAL CONNECT"	4
"BRKAWAY PRAC"	4
"BREAKAWAYS"	4
DUMP AP AR MODE	13
"CLEAR TANKER"	4
"SET POST REF CL"	4
Recovery	
CALL DESCENT CLIST	6
SET ALT	12
SET AIRBRAKES	12
DUMP AP	13
DRAG CHUTE	14
CHECK ALL HYDRAULIC	15
CHECK CROSSWIND CRAB	15
CALL CHECKLIST	6

MISSION TWO--LOWLEVEL

Task Brief	Task* Number
Takeoff	
REVIEWS TAKEOFF CHECKLIST	1
RELEASES BRAKES	2
SET ENGINE STALL PREVENTION SWITCH TO CLIMATIC	3
CALLS "70 KNOTS, NOW"	4
CALLS "COMMITTED"	4
SELECTS FLIGHT DIRECTOR FOR HEADING	5
"WATER-OUT EPR"	4
CALLS AFTER TAKEOFF-CLIMB CHECKLIST	6
SELECTS FLIGHT DIRECTOR FOR NAV GUIDANCE	5
ENGAGES AUTOPILOT TO CAPTURE DESIRED HEADING	7
RESETS ALTIMETERS	8
SET THRUST GATE	9
Lowlevel	
"GET LL DESC CL"	4
TURN ON EVS TA VIO	8
RAD ALT TO 800 FT	8
SET ALTS	8
DUMP AP	13
AP TO LL	10
CHK ALTS	15
SET ALTS	8
CHECK GEAR, FLAPS UP	15
"GET TA CHCKLST UP"	4
SET ALT HOLD AP	16
CHK ALTS	15
"YOUR AIRPLANE"	4
COMPARE STAB MODES	15
SET STAB REF SEL.	5
PROFILE SET	8
READ RAD ALT.	15
SET CL PLANE CAL VAL	8
SET ALTS	8
SET STAB REF SEL	9
SET CL PLANE TO ALT	5
SET RADALT CURSOR	8
"I HAVE THE AC"	4
TRSRNS BOMB REL LITES	17
Recovery	
CALL DESCENT CLIST	6
SET ALT	12
SET AIRBRAKES	12
DUMP AP	13
DRAG CHUTE	14
CHECK ALL HYDRAULIC	15
CHECK CROSSWIND CRAB	15
CALL CHECKLIST	6

*TASK NUMBER KEY

Reviews Takeoff Checklist	1
Releases Brakes	2
Set/Select/Engage/Disengage (A/M 2)	3
Instruction	4
Set/Select/Engage/Disengage (V/M 3)	5
Checklist	6
Set/Select/Engage/Disengage (V/V 3)	7
Set/Select/Engage/Disengage (V/M 1)	8
Set/Select/Engage/Disengage (V/M 2)	9
AP/AR (V/M 3)	10
AP/AR (V/V 2)	11
Set/Select/Engage/Engage (A/M 1)	12
AP/AR (V/M 1)	13
Drag Chute	14
Checks	15
Set/Select/Engage/Disengage (V/M 3)	16
Set/Select/Engage/Disengage (V/V 2)	17

At this point the tasks were then grouped into types of tasks based on whether they accessed the same equipment, had the same input/output mode, required the same number of steps to complete and were assigned the same anthropometry index. Numbers with a corresponding key were used to identify like tasks. Each task which occurred more than once in either mission was included on the Candidate Task List (Table 13).

Table 13. CANDIDATE TASK LIST

1. Verbal Instruction
2. Set/Select/Engage/Disengage (V/M 3) [9]
3. Checklist
4. Set/Select/Engage/Disengage (V/M 1)
5. Set/Select/Engage/Disengage (V/M 2)
6. Adjust AP/AR (V/M 3)
7. Set/Select/Engage/Disengage (A/M)
8. Adjust AP/AR (V/M 1)
9. Checks

B. MODULE TWO

This module requires that pilots be surveyed and a Pilot Utility Index (PUI) be assigned to each of the tasks listed in Table 13. For the purposes of this example, it was assumed that the pilots had been questioned and the PUI(s) listed in Table 14 obtained.

[9] The information in parentheses indicate the input/output mode and anthropometry index of the task listed. This information is provided when tasks with identical titles are included.

Table 14. PILOT UTILITY INDEX

	Task	PUI
1.	Verbal Instruction	4.2
2.	Set/Select/Engage/Disengage (V/M 3)[10]	5.2
3.	Checklist	3.5
4.	Set/Select/Engage/Disengage (V/M 1)	4.8
5.	Set/Select/Engage/Disengage (V/M 2)	4.8
6.	Adjust AP/AR (V/M 3)	5.5
7.	Set/Select/Engage/Disengage (A/M)	4.8
8.	Adjust AP/AR (V/M 1)	5.0
9.	Checks	5.5

C. MODULE THREE

Module Three contains the performance specifications developed for use in completing the optimization in module four. A conversion factor was obtained for each task listed on Table 13 based on the number of steps the each task requires.

D. MODULE FOUR

The optimization problem for this example has the same formulation as described in module four of the model description contained in Chapter II. The only exception is that the type of task indicator is not necessary since no single tasks remained for consideration after the filters were applied.

As mentioned in Chapter II, the LINDO software package by LINDO, Inc was used to solve this problem. Figure 8

[10]The information in parentheses indicate the input/output mode and anthropometry index of the task listed. This information is provided when tasks with identical titles are included.

contains the LINDO problem formulation. For each mission, C (the maximum total additional time allowed for voice processing), was calculated by deciding the total amount of time which could be spent in voice information processing channels during a mission and subtracting from it the time currently consumed in these channels by non-candidate tasks. The time was calculated by using the conversion factor calculated above along with the reaction times contained in Table 3. The utility value T_{ijk} was calculated by summing the reaction time savings (conversion factor x appropriate Table 5 entries x number of times tasks performed during the mission), pilot utility index, and the anthropometry index.

Figure 9 contains the solution produced by the LINDO package. Tasks two through eight were selected to be converted to the audio/vocal mode while task nine was selected for conversion to the audio/manual mode. Since task one contains a fractional value, it is dropped from conversion consideration. This combination of tasks are now used by the engineer to begin design and testing.

```
MAX -26.88 X111 + 4.2 X112 + 10.5 X113 + 61.6 X114 + 8.2 X211 + 12.64 X212
 + 19.53 X213 + 27.16 X214 - 3.16 X311 + 3.5 X312 + 4.85 X313 + 15.8 X314
+ 5.8 X411 + 10.24 X412 + 13.14 X413 + 18.44 X414 + 6.8 X511 + 9.02 X512
+ 10.47 X513 + 12.8 X514 + 8.5 X611 + 12.94 X612 + 15.84 X613 + 21.14 X614
- 1.54 X711 + 4.9 X712 + 5.8 X713 + 18.44 X714 + 6.0 X811 + 10.44 X812
+ 13.34 X813 + 18.64 X814 + 2.06 X911 + 6.5 X912 + 7.4 X913 + 14.7 X914
- 11.34 X121 + 4.2 X122 + 7.35 X123 + 32.9 X124 + 8.2 X221 + 12.64 X222
+ 19.53 X223 + 27.16 X224 - 3.16 X321 + 3.5 X322 + 4.85 X323 + 15.8 X324
+ 5.8 X421 + 25.78 X422 + 38.83 X423 + 62.68 X424 + 6.8 X521 + 11.24 X522
+ 14.14 X523 + 19.44 X524 + 8.5 X621 + 10.72 X622 + 12.22 X623 +14.82 X624
- 1.54 X721 + 4.9 X722 + 5.8 X723 + 18.44 X724 + 6.0 X821 + 10.44 X822
+ 13.34 X823 + 18.64 X824 - 6.82 X921 + 6.5 X922 + 9.2 X923 + 31.11 X924
ST
X111 + X112 + X113 + X114 < 1
X211 + X212 + X213 + X214 < 1
X311 + X312 + X313 + X314 < 1
X411 + X412 + X413 + X414 < 1
X511 + X512 + X513 + X514 < 1
X611 + X612 + X613 + X614 < 1
X711 + X712 + X713 + X714 < 1
X811 + X812 + X813 + X814 < 1
X911 + X912 + X913 + X914 < 1
219.66 X111 + 219.66 X112 + 213.6 X113 + 162.26 X114 +
35.82 X211 + 31.38 X212 + 30.48 X213 + 23.18 X214 +
53.73 X311 + 47.07 X312 + 45.72 X313 + 34.77 X314 +
35.82 X411 + 31.38 X412 + 30.48 X413 + 23.18 X414 +
17.91 X511 + 15.69 X512 + 15.24 X513 + 11.59 X514 +
35.82 X611 + 31.38 X612 + 30.48 X613 + 23.18 X614 +
35.82 X711 + 31.38 X712 + 30.48 X713 + 23.18 X714 +
35.82 X811 + 31.38 X812 + 30.48 X813 + 23.18 X814 +
35.82 X911 + 31.38 X912 + 30.48 X914 + 23.18 X914 < 312
X121 + X122 + X123 + X124 < 1
X221 + X222 + X223 + X224 < 1
X321 + X322 + X323 + X324 < 1
X421 + X422 + X423 + X424 < 1
X521 + X522 + X523 + X524 < 1
X621 + X622 + X623 + X624 < 1
X721 + X722 + X723 + X724 < 1
X821 + X822 + X823 + X824 < 1
X921 + X922 + X923 + X912 < 1
125.37 X121 + 109.83 X122 + 106.68 X123 + 81.13 X124 +
35.82 X221 + 31.38 X222 + 30.48 X223 + 23.18 X224 +
53.73 X321 + 47.07 X322 + 45.72 X323 + 34.77 X324 +
161.19 X421 + 141.21 X422 + 137.16 X423 + 104.31 X424 +
35.82 X521 + 31.38 X522 + 30.48 X523 + 23.18 X524 +
17.91 X621 + 15.69 X622 + 15.24 X623 + 11.59 X624 +
35.82 X721 + 31.38 X722 + 30.48 X723 + 23.18 X724 +
35.82 X821 + 31.38 X822 + 30.48 X823 + 23.18 X824 +
107.46 X921 + 94.14 X922 + 91.44 X924 + 69.54 X924 < 390
X111-X121=0
X112-X122=0
X113-X123=0
X114-X124=0
X211-X221=0
X212-X222=0
X213-X223=0
X214-X224=0
X311-X321=0
X312-X322=0
X313-X323=0
X314-X324=0
X411-X421=0
X412-X422=0
X413-X423=0
X414-X424=0
X511-X521=0
X512-X522=0
X513-X523=0
X514-X524=0
X611-X621=0
X612-X622=0
X613-X623=0
X614-X624=0
X711-X721=0
X712-X722=0
X713-X723=0
X714-X724=0
X811-X821=0
X812-X822=0
X813-X823=0
X814-X824=0
X911-X921=0
X912-X922=0
X913-X923=0
X914-X924=0
END
```

Figure 8. Lindo Mathematical Formulation [11]

---

[11] X_{ijk} with i = Candidate Task
j = Mission Number
k = Input/Output Mode

LP OPTIMUM FOUND AT STEP 45

OBJECTIVE FUNCTION VALUE

1) 413.208300

VARIABLE	VALUE	REDUCED COST
X111	.000000	154.809700
X112	.000000	.000000
X113	.000000	.000000
X114	.922840	.000000
X211	.000000	.000000
X212	.000000	.000000
X213	.000000	.000000
X214	1.000000	.000000
X311	.000000	45.802280
X312	.000000	31.763500
X313	.000000	.000000
X314	1.000000	.000000
X411	.000000	76.881520
X412	.000000	.000000
X413	.000000	.000000
X414	1.000000	.000000
X511	.000000	.000000
X512	.000000	.000000
X513	.000000	.000000
X514	1.000000	.000000
X611	.000000	.000000
X612	.000000	.000000
X613	.000000	12.151510
X614	1.000000	.000000
X711	.000000	45.781520
X712	.000000	31.855670
X713	.000000	.000000
X714	1.000000	.000000
X811	.000000	.000000
X812	.000000	.000000
X813	.000000	.000000
X814	1.000000	.000000
X911	.000000	.000000
X912	.000000	.000000
X913	1.000000	.000000
X914	.000000	.000000
X121	.000000	11.340000
X122	.000000	119.529700
X123	.000000	106.550400
X124	.922840	.000000
X221	.000000	45.281520
X222	.000000	33.815670
X223	.000000	19.511510
X224	1.000000	.000000
X321	.000000	3.160000
X322	.000000	.000000
X323	.000000	28.277270
X324	1.000000	.000000
X421	.000000	.000000
X422	.000000	49.875670
X423	.000000	33.401510
X424	1.000000	.000000
X521	.000000	22.320760
X522	.000000	14.367830
X523	.000000	9.755755
X524	1.000000	.000000
X621	.000000	26.321520
X622	.000000	17.075670
X623	.000000	.000000
X624	1.000000	.000000
X721	.000000	1.540000
X722	.000000	.000000
X723	.000000	29.531510
X724	1.000000	.000000
X821	.000000	32.641520
X822	.000000	21.175670
X823	.000000	14.851510
X824	1.000000	.000000
X921	.000000	42.221520
X922	.000000	21.875670
X923	1.000000	.000000
X924	.000000	2.041512

Figure 9. Lindo Solution

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