Decision Support System for Logistics Systems Analysis Using Image Theory and Work Domain Analysis

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In this study, image theory and work domain analysis were used to develop an interactive decision support system for sortie generation tasks in an Air Force aircraft maintenance unit. Aircraft maintenance personnel were charged with creating a short list of aircraft for deployment using either maintenance information alone or maintenance information with the interactive decision support system. Results were compared with a deployment list developed by expert aircraft maintenance superintendents. The deployment lists generated with the interactive decision support system more closely resembled the experts' list and took less time to create than those generated using maintenance information alone. These results show the viability of the methodology outlined in this study for creating decision support systems in complex logistics planning.

Keywords: Air Force logistics, interactive decision support system, image theory

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1. Introduction

Today's logistics community has become extremely proficient in the production and collection of data for the purposes of documentation and decision making. However, the journey from data to knowledge to decision is, in many instances, a long and complex one. Logistics systems are complex due to the interactions between their various subsystems (computational complexity) and the uncertain nature of these interactions (gnosiological complexity) [1]. Decision support systems (DSSs) provide opportunities to integrate the decision maker's knowledge with applicable database components in a synergistic way, using data models to reduce complexity and help frame problems. A DSS serves to conduct the decision maker through a problem space. It does not replace a decision maker; rather, a DSS provides a decision maker with relevant information so that the best choices can be selected. No one will dispute that having the best choices easily at hand is a good thing; but with a complex system it is often difficult to identify and integrate relevant information and then to present it to the decision maker in a structured manner. The difficulty is that in semi-structured decision tasks, where DSSs are badly needed, it is challenging for designers to reliably and consistently produce an integrated development environment conducive to good decision making. The DSS must enable the decision maker to perform the functions at which humans are proficient (i.e., recognition and framing of problems) while helping to forgo data manipulation (at which computers excel). This study outlines how image theory and work domain analysis can be used to capture the mental schemas of subject-matter experts and illustrates the approach of converting that knowledge into working models for DSSs in the domain of U.S. Air Force Logistics.

2. Background

2.1 Air Force Logistics System

With changing world threat conditions, increasing budgetary constraints, and the need for a more responsive, capable logistics capacity, the U.S. Air Force has embarked on a new course of operations that marks the return to expeditionary, light, and lean applications of force. The Focused Logistics operational concept of Joint Vision 2010 [2] and the Joint Force Operational Concepts of the U.S. National Military Strategy of 2004 [3] outline the need for a greater capacity to launch worldwide military actions based from the continental United States instead of the present-day reliance on large-scale forward-basing of supplies and equipment overseas.

The Air Expeditionary Force (AEF) is a unique, task-organized, tailorable war-fighting force composed of organic airpower assets capable of supporting operations anywhere in the world [4]. It provides combatant commanders with flexible, rapid-response force packages capable of supporting a wide spectrum of operations while reducing the time allowed to perform tasks [5]. This concept requires the ability to deploy and employ quickly, to adapt rapidly to changes in the scenario, and to sustain operations indefinitely. To meet the demanding time lines, units must be able to deploy and set up logistics production processes quickly. Deploying units will, therefore, have to minimize deployment support. This, in turn, demands the support system be able to ensure the delivery of sufficient resources when needed to sustain operations [5].

The successful employment of crisis action plans for logistical operations in support of the AEF depends heavily on the "transition from a situation in which functional stovepipes exchange vital information late in the cycle, if at all, to a collaborative environment supported by tools that facilitate communication and decision making" [6]. Part of the solution is to incorporate joint decision support tools that "will aggregate, categorize, and depict data elements in a format easy to use and understand" [2].

Decision support tools can come in many forms and may be distinguished by their level of interaction with the decision maker. Low-interaction support tools utilize the computer's ability to perform complex mathematical processes in a relatively short period. These low-interaction support tools depend heavily on the ability of the developer to identify and understand the relationships between several objects of interest, expressing them in mathematical arrangements that can be optimized for the best combination of objects in the system. Optimized solution generators attempt to take advantage of the computer's ability to evaluate a significantly large number of combinations to arrive at a desirable solution.

A generalized framework for a DSS is depicted in Figure 1, showing the identity and relationships between the three major components of a DSS (the database, the data reduction model, and the user interface) as they relate to the decision maker. Information is made available through the database, interpreted to support particular decision spaces in the data reduction model, and presented to the decision maker in the interface. Not shown in the figure is the decision maker's knowledge base, or what the user knows about the decision and about how to use the device. In U.S. Air Force logistics, the human is not generally considered to be part of the DSS, and the decision maker's intuitive

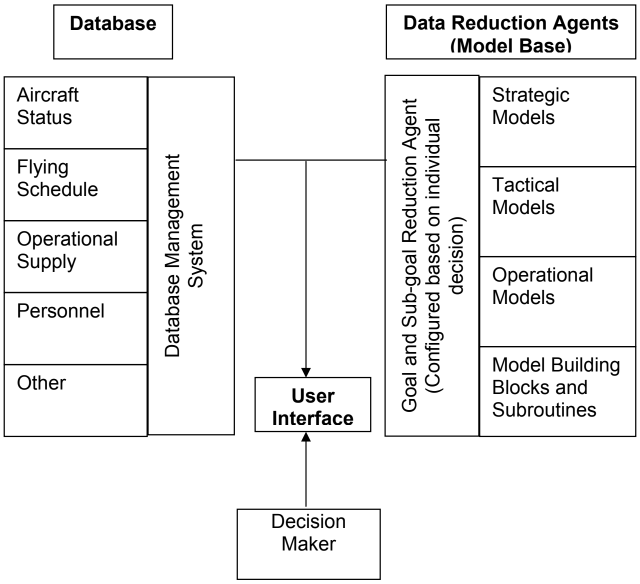


Figure 1. Relationships between the major components of an Air Force logistics DSS: database, data reduction agents, and user interface

knowledge is not included as a formal part of the system. For this case study, the database component of the DSS poses a particular challenge, because it is not a fully integrated component but consists of many separate systems.

2.2 Database Component in Context

Within the context of U.S. Air Force logistics systems, the database shown in Figure 1 is comprised of many individual items. These data groupings represent the aircraft status, flying schedule, operational supply, and other items including the status of spare parts, personnel, individual activities in progress, fuel, ammunition, maintenance, planning and scheduling, resource availability, facilities, and managerial policy and direction. These data groupings interact in such a way that it is difficult to separate each database from the others. To demonstrate this and to decrease the amount of confusion in explanation, this research focuses on front-line maintenance units that are responsible for the sortie generation of aircraft in a fighter squadron. It is also helpful to note that each of these databases can significantly differ based on the type of aircraft or weapon system for which an individual unit is responsible. For example, a General Dynamics F-16 requires different parts, specialists, documentation, fuel, ammunition, and scheduling than a Republic A-10. This information can be found by consulting the millions of pages of documentation associated with the individual aircraft. In designing a DSS, this factor causes difficulty when each of the individual weapon systems does not have standardized information processing systems to manage the data. A mechanism for filtering the information to a more relevant set using a model-based approach would therefore be extremely useful.

2.3 Data Reduction Models

Models may be categorized based on their purpose, treatment of randomness, and generality of application. Vicente [7] defines a model to be a description of a natural system using some type of formalism consisting of variables and the constraints between those variables. This definition can be further refined for this paper as an abstraction of a system to support decision making.

Beach's image theory [8] provides a means to understand the information gathered in work domain analysis that will map cognitive elements to a formalistic decision process. According to Beach [8], decision makers use prior knowledge (images) to develop principles that guide decisions about what to do (goals) and how to do it (plans). Images developed by a domain expert come together to create a sequential iterative process for completing particular tasks. These tasks are to be identified using a descriptive, human-centered approach instead of using a top-down, normative prescription of some ideal process. The identified process should allow the decision maker to interactively perform parsing tasks (compatibility tests) as well as interactive benefit analysis (profitability tests). The rejection threshold and repertory of strategies can be identified by experimentation, observation, or interview. Inclusion of the elements of image theory in a logistical DSS facilitates the decision maker's natural inclination toward determining the correct solution and, as such, should simplify the decision-making process.

3. Methods

3.1 Processes and Activities (Sortie Generation)

The mental schema for model development was based on two major components: 1) work domain analysis using open-ended interviews and observations at two airbases, and 2) decision-making activity analysis using observation and semi-structured interviews with production superintendents of an operational F-16 maintenance unit. The production superintendents are considered to be expert decision makers in this context.

In this research, the work domain analysis was

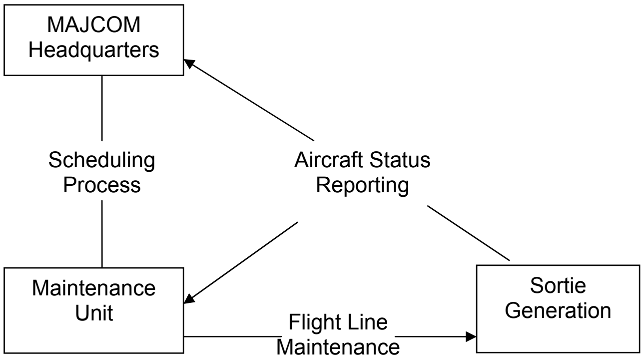


Figure 2. Significant maintenance processes

applied to the specific problem of U.S. Air Force aircraft sortie generation. The process and activities associated with sortie generation define the properties necessary and sufficient for control of physical work activities and use of aircraft to perform the mission. Sortie generation experts utilize an iterative process of coordinating activities between the maintenance unit, the major command headquarters, and the aircraft scheduling unit (all of which could be geographically separated) to achieve the organizational objective. These processes and activities comprised the test bed for this study.

Work domain analysis was accomplished by identifying two levels of abstraction: general work activities and functions, and problem-specific processes and activities of a U.S. Air Force operations squadron maintenance unit. General work activities of the maintenance unit include day-to-day planning, repairs, routine (phase) inspections, and documentation of activities. Problem-specific processes and activities for individual missions include, but are not limited to, aircraft scheduling, aircraft status reporting, and flight line maintenance processes for specific aircraft; see Figure 2. These processes transfer the direction from higher headquarters into the day-to-day activity of a flying unit and provide feedback to upper management. Each of these processes was taken into account in the development of an interactive decision support system (IDSS) to assist in sortie generation as an individual decision-making activity.

3.2 Decision-Making Activity Analysis and DSS Design

One prototypical production task—choosing which aircraft should be deployed as a part of a rotational cycle—was chosen from the core production superintendent's responsibilities to demonstrate the decision-making activity endemic to the sortie generation domain. As a representation of a typical mission, six aircraft out of the entire squadron were to be chosen for deployment.

Interviews identified two types of choice strategies dependent upon duration and utilization of aircraft while on deployment. Choice strategy 1 involved the selection of six aircraft for deployment when phase inspections were not expected to be performed at the deployment location. Subject-matter experts utilized this strategy if the expected total time of aircraft flight operations was 100 hours or less. Choice strategy 2 involved selection of aircraft when utilization at the deployment location suggested that phase inspections would be performed during deployment. Only choice strategy 1 was incorporated into the DSS, because the intended use of the DSS in this research was on rapid-response, short duration actions designed to expedite operations and holding actions before the arrival of more permanent forces. The emphasis was on speed and projection of force rather than on full-scale, large deployments.

One continuous and seven discrete subtasks were found corresponding to an image theoretical expression of a production superintendent's choice strategy. Identification and elaboration of this framework led to the representation of the process by means of adoption and progress decisions. Relevant subtasks were further categorized by types of decision tests performed and were adapted to support the overarching decision process. These subtasks, listed in Table 1, were analyzed to determine the rejection threshold and the variables associated with the profitability tests. Decision tasks served, first, to eliminate aircraft from consideration that did not meet specified criteria (compatibility test) and, second, to choose the best-suited aircraft based on subjective expected utility (profitability test). Compatibility tests performed by the production superintendents resulted in removal of aircraft when the numbers of violations in aircraft mission capability (aircraft status), repair history, and phase inspection times exceeded the minimum threshold values for the strategy being used. Profitability tests evaluated aircraft based on scheduled maintenance, outstanding unscheduled maintenance, time to phase inspection, aircraft configuration, and aircraft location.

3.2.1 Subtask 1: Aircraft Status

During the aircraft status compatibility test, the production superintendent excluded all aircraft from consideration that were designated non-mission capable (NMC) or partially mission capable (PMC) if at least twelve aircraft remained to pass to the next compatibility test. NMC or PMC aircraft were not likely to change status within the 24-hour planning deadline

Table 1. Subtasks for the production superintendents' choice strategy

Evaluation	Evaluation Order	Decision Type	Test Type	Information Requirements
Aircraft Status	1	Adoption	Compatibility	Mission capability rating, aircraft history
Phase Inspection #1	2	Adoption	Compatibility	Time until phase inspection, phase month, conflicting activities
Scheduled Maintenance	3	Adoption	Profitability	All known scheduled maintenance actions for the period of the deployment
Unscheduled Maintenance	4	Adoption	Profitability	Outstanding repair actions, time to complete repairs, impact of repair actions
Phase Inspection #2	5	Adoption	Profitability	Time to phase inspection
Aircraft Configuration	6	Adoption	Profitability	Current configuration of aircraft
Aircraft Location	7	Adoption	Profitability	Location of aircraft relative to the airfield
Monitor Goal State	Continuous	Progress	Compatibility	Mission update

called for by mission requirements. Aircraft were also eliminated based on repair history considerations. An aircraft with a history of repeat or recurring problems may not have been able to successfully execute a transatlantic crossing or to fulfill its mission once at the employment location. Repeat or recurring maintenance actions that had no known explanation did not affect the mission capability rating of an aircraft if the problem was not immediately present, but had to be considered likely to affect wartime efforts if the problem was in a critical system. This characteristic, commonly referred to as the aircraft's "personality," denoted the increased likelihood of specific maintenance actions due to prior repairs and factory defects. The complexity and interrelation of aircraft subsystems prohibited the detection and repair of all system failures and could not be ignored.

3.2.2 Subtask 2: Phase Inspection #1

The phase inspection compatibility test took into account the time remaining before an aircraft was due for major scrutiny (which occurs after 300 hours of flight time), taking it off the list of available assets. If an aircraft came due for phase inspection while on deployment, the aircraft was not available for combat missions and was held until maintenance personnel could fit the inspection into an already crowded schedule. Therefore, the rejection threshold for this test was the expected total number of hours aircraft were needed to fly during deployment. If aircraft were deployed for an extended period, phase inspection could not be avoided, but every effort was made to reduce the workload of maintenance personnel while on deployment. Phase inspection cycles were generally displayed on a phase flowchart depicting in descending order the tail number of aircraft by time remaining until inspection was due. A line was drawn showing the ideal graduated descent enabling aircraft to enter phase incrementally. Incremental entry into phase enabled sufficient aircraft to remain in service to accomplish mission requirements. Expert decision makers, at this stage, generally eliminated from consideration any aircraft that were due for phase inspection within flight time allotted for the deployment. Remaining aircraft were included for consideration in the next stage of profitability tests. If the number of aircraft surviving the two compatibility tests was less than the number of aircraft needed for deployment, the current choice strategy was abandoned and a new strategy was adopted.

3.2.3 Subtask 3: Scheduled Maintenance

The first profitability test conducted by production superintendents was a review of the importance, frequency, and density of scheduled maintenance items to be performed on the aircraft. Examples of common scheduled maintenance items include wash and corrosion control checks, ten-hour throttle grip/flame sensor inspection, 50-hour miniforce check, 25-hour borescope inspection, and 50-hour borescope inspection of aircraft blade retainer. Scheduled inspections varied between aircraft mission design series and were determined by manufacturers' specifications. Regular inspections enabled the safe and reliable operation of aircraft and long service life. Aircraft due for major inspections of critical systems were ranked higher in importance than those due for inspections involving non-critical systems. Importance of aircraft scheduled events was rated by subject-matter experts for this particular task to reflect the impact the item would have on deployment sortie generation. Rated items were categorized into three-color codes: red (high importance), yellow (medium importance), and green (low importance). Time to conduct the inspection and equipment involved in the process were also major considerations. The expert decision makers utilized the aircraft schedule to make the assessment, rank-ordering aircraft from best to worst.

3.2.4 Subtask 4: Unscheduled Maintenance

Unscheduled maintenance review refers to the evaluation of aircraft based on broken, cracked, or out-of-limit components found during inspection or reported by pilots. Aircraft sent on deployment should necessarily be as free of problems as possible; therefore, a thorough review of outstanding repairs was necessary. Aircraft were ranked, from best to worst, based on the time to repair the item and the manpower necessary to complete the work order. Repairs to non-mission essential components, regardless of the time and manpower needs, were ranked lower than mission-essential component repairs.

3.2.5 Subtask 5: Phase Inspection #2

Phase inspection times were reevaluated in the next stage to determine aircraft that had more time until inspection was due. Aircraft that would not come due for inspection within the time frame of the deployment were ranked higher than those requiring more immediate attention. Aircraft best meeting this need were located from left to right on the phase flowchart and were easily identified. Any times that were over the projected deployment time satisfied the requirement, but those aircraft with greater time until inspection were superior due to unforeseen occurrences that might have affected the length of time an aircraft remained in theater.

3.2.6 Subtask 6: Aircraft Configuration

Next, aircraft configuration was evaluated to determine those aircraft meeting the mission configuration requirement before deployment. Configuration refers to the presence or lack of armaments, weapons, or specific mission systems on the airframe. For example, if aircraft are needed for overseas deployment, wing tanks are used to extend the range an aircraft can fly. If wing tanks are already present on the airframe, less time is needed to configure the aircraft for duty. The expert decision makers ranked aircraft based on the time and effort necessary to reconfigure aircraft for duty.

3.2.7 Subtask 7: Aircraft Location

Aircraft were also evaluated to determine the most expedient airfield location for preflight activities and launch. Aircraft requiring loading of armaments were required to comply with regulations concerning distance from critical facilities and other assets in case of emergency. Similarly, aircraft requiring fuel needed to be away from sensitive areas. With larger airframes, movement on the airfield could be extremely difficult due to space limitations and availability of equipment used in the transfer. Smaller airframes, like the F-16, were more readily accommodated. Aircraft were rank-ordered by the effort needed to comply with regulation limits during preflight and launch activities.

3.2.8 Continuing Subtask: Goal State

Finally, the expert decision makers continually evaluated the progressive creation of the available aircraft list. A comparison of current decision progress against the internal image constituents (value, trajectory, and strategic images) impacted the determination of satisfactory progress. In general, this related to the trust decision makers had in the process utilized to make the decision and the efficacy of the projected outcome. Solution sets not conforming to internal measures of validity and confidence were not accepted, and a new approach to the problem was initiated.

3.3 Model Implementation

Implementation of these image theoretical decision structures into the IDSS utilized a structured interactive approach, limiting the novice decision maker (the intended *user* of the DSS) to the specified sequence of events and types of decisions, but not limiting the user's input within the eight subtasks. Adoption decisions were assisted by employing user-input text fields to either exclude aircraft from a list or rank aircraft in an ordered list. Progress decisions were accommodated using a feedback mechanism displaying a cumulative rank-ordered list of aircraft as the decision process proceeded. Users could effectively account for changes to internal image states by overriding computer suggestions at any point.

Implementation of the model was accomplished using Sun Microsystems's object-oriented programming language, Java, to develop a PC-based system. In order to evaluate the IDSS, a simulated real-time database was used. Major features of the airbase simulation infrastructure included a random number generator, statistical distribution calculator, event calendar, simulation clock, failure generator, and main simulation loop. The failure generator incorporated major inspection cycles, unscheduled failures to system components, aborted sorties due to weather and scheduling conflicts, and delays due to part unavailability, manning difficulties, and mission restrictions. The assignment of the simulation was to generate as many sorties as possible while conforming to realistic limitations. Typical restrictions included a five-day flying schedule and a ten-hour flying day. Aircraft were flown for 18 weeks to fully develop the repair histories and establish a "personality" pattern for each individual aircraft. Generated aircraft datasets were eliminated from use if flight time was low and unscheduled maintenance actions were not uniformly distributed. The simulation shared major components with the Java-based architecture for developing interactive simulation for logistics systems, as outlined by Narayanan et al. [9].

The IDSS used computer suggestions to portray the choice strategy of the production superintendents to the user and to assist him or her in making a decision. An information presentation only (IPO) tool was used as a control in the evaluation of the IDSS. Utilization of the IPO tool as a substitute for the data collection process used in an actual aircraft squadron was necessary to eliminate confounding variability due to individual differences in data collection and prior knowledge. Users frequently collected aircraft data for the selection task by personal communication with pertinent organizational elements [10]. Collection times could vary due to collection method, interfering tasks, process deficiencies, and prior knowledge of aircraft conditions. It would have been increasingly difficult to separate task performance from non-essential variability in actual field conditions. For these reasons, an IPO collection tool was constructed to provide more realistic baseline measurements.

The IPO tool consisted of a series of informational screens with an accompanying "scratch pad" that served as an external memory storage device. The scratch pad was a blank list, ordered from one to eighteen. This list was external to the informational screens in that it was always visually present as the user navigated through the screens. The user interacted with the information screens by freely selecting the tabs associated with each of the screens. Users annotated aircraft tail numbers to the scratch pad by selecting an individual tail number from the information screen and assigning it to a list position on the scratch pad. Users navigated through the information, compiling and amending the aircraft list, and finished the task by selecting the END button. IPO screens included Phase Info, Aircraft Status,

Table 2. IPO and IDSS presentation methods

	Test	IPO	IDSS
Compatibility Tests	Aircraft Status		• Suggested removal of aircraft if FMC status is violated
	Phase Inspection #1	Color coding of deviations from standard	• Color coding (red, blue) of deviations from standard • Suggested removal of aircraft if time until phase is less than expected deployment duration
Profitability Tests	Scheduled Maintenance	Color coding of importance rating	• Color coding (red, yellow, green) of importance rating • Aircraft ranked based upon Σ (importance rating) × (duration) × (frequency)
	Unscheduled Maintenance	None	• Aircraft ranked based upon lowest time to complete repairs
	Phase Inspection #2	Color coding of deviations from standard	• Color coding (red, blue) of deviations from standard • Aircraft ranked based upon highest time until due for phase inspection
	Configuration	None	• Aircraft ranked based upon lowest time to achieve desired configuration
	Location	Graphical map of airfield with positions listed	• Graphical map of airfield with positions listed • Aircraft ranked based upon lowest time to achieve desired location on ramp
	Process Constraints	None	• Enforced step-by-step process

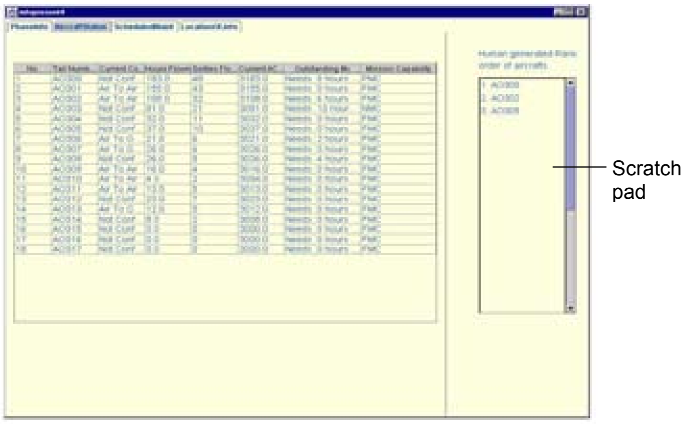


Figure 3a. Screen shot of the aircraft status information task for IPO display

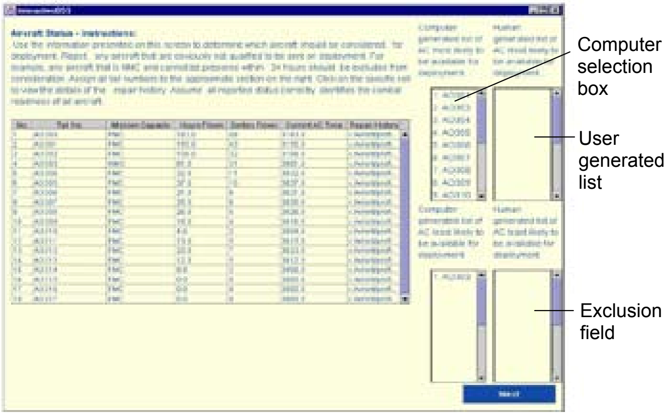


Figure 3b. Screen shot of the aircraft status information task for IDSS display

Scheduled Maintenance, and Location of Jets.

Differences between the two presentation methods, IPO and IDSS, are highlighted in Table 2 and show the inclusion or exclusion of the identified image theoretical constructs identified in the choice strategy. Aside from these key differences, the user interfaces for the two methods were similar in layout. In the sections following the table, the individual elements of the user interface are described in more detail.

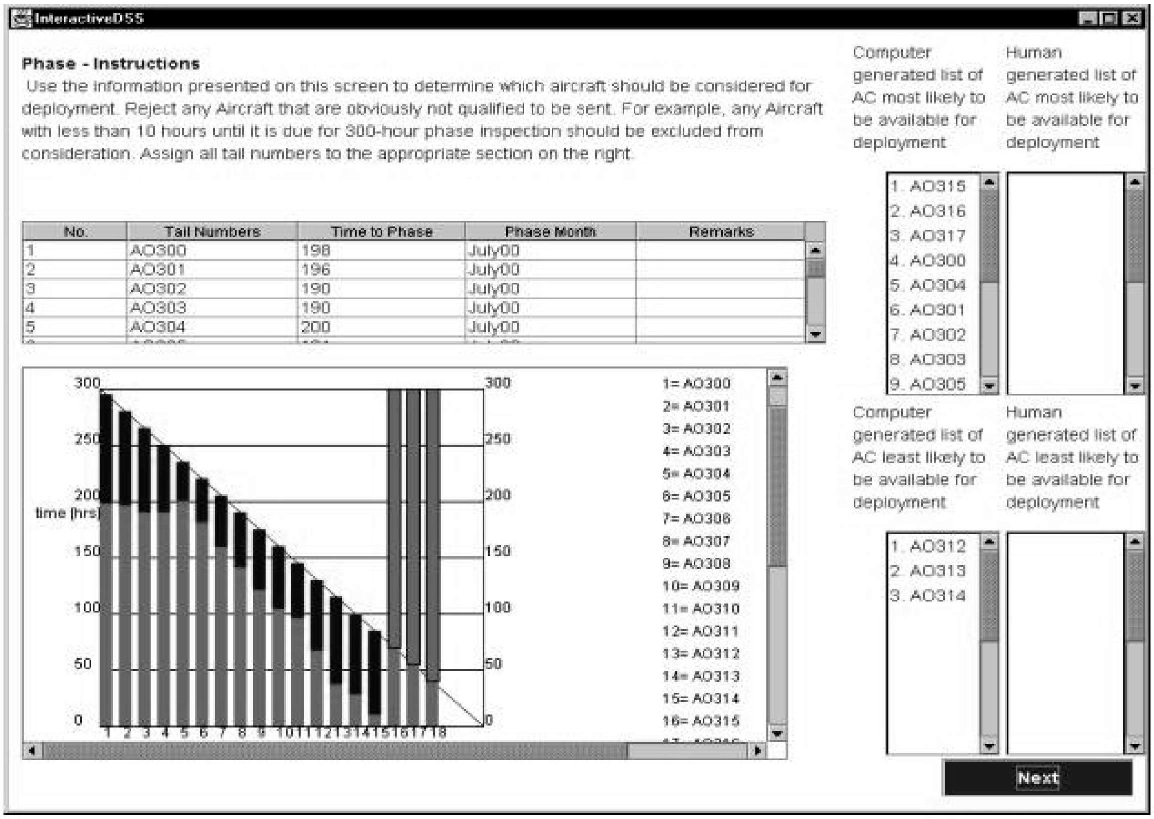
The first compatibility test for the decision-making task was based on aircraft status information. As shown in Figure 3a, the IPO screen presents the user with the information only, and a text field that acts like a scratch pad for the user input. Figure 3b displays the information provided to the user for this purpose in the case of the IDSS scenario. Pertinent data necessary to determine the true mission capability of all squadron aircraft were shown on the screen. Users perused the spreadsheet and activated the aircraft history screen by clicking on the individual aircraft repair history field. Aircraft that did not meet minimum criteria were identified; the user could select the correct aircraft tail number from the list and move it to the box provided for exclusion. A computer suggestion box was provided in the IDSS condition, illustrating the model's selection of aircraft for exclusion. Users signified agreement or disagreement with computer suggestions by entering aircraft tail numbers into the exclusion field. The process progressed to the next screen when the NEXT button was selected. Only user-input values were incorporated into the remainder of the program, and any user-excluded tail numbers were eliminated from consideration for the duration of the program.

The next compatibility test (see Figure 4) involved removal of aircraft due to time-to-phase inspection. The bar graph was color coded to indicate time-to-phase inspection values. Red indicated a short time to phase inspection, while blue indicated a long time. The computer-generated suggestion removed aircraft from the working list of available aircraft if the time-to-phase inspection value was less than 40 hours. Users signified their approval or disapproval of computer suggestions by selecting aircraft tail numbers from the spreadsheet and including them in the text box for removal.

The first profitability test (see Figure 5) utilized information concerning schedule maintenance actions. Users compared the list of available aircraft against the density and importance of scheduled maintenance items over the duration of the deployment period. Items were color coded to represent various importance ratings. Red indicated important inspections that would possibly interfere with aircraft use in deployment operations. Yellow indicated moderate task importance. Green indicated scheduled tasks that could possibly be delayed, and that had limited impact on deployment availability. The user was asked to rank-order the aircraft tail numbers from best to worst in the text field provided. Data entry was accomplished by selecting a tail number from the list and moving it to the appropriate column. Computer suggestions were provided in the left-most column.

Outstanding unscheduled maintenance items were evaluated by utilizing aircraft history records and time-to-complete projections (see Figure 6). Aircraft were rank-ordered based on the severity of the outstanding repair action, the time to complete, and the impact repair would have on the deployed mission. Users were tasked to provide an ordered list common to all profitability test subtasks.

Figure 7 displays the screen utilized for the second phase inspection evaluation. Users rank-ordered aircraft tail numbers based on the time-to-phase inspection values provided in the accompanying chart.



Phase - Instructions

Use the information presented on this screen to determine which aircraft should be considered for deployment. Reject any Aircraft that are obviously not qualified to be sent. For example, any Aircraft with less than 10 hours until it is due for 300-hour phase inspection should be excluded from consideration. Assign all tail numbers to the appropriate section on the right.

No.	Tail Numbers	Time to Phase	Phase Month	Remarks
1	AO300	198	July00	
2	AO301	196	July00	
3	AO302	190	July00	
4	AO303	190	July00	
5	AO304	200	July00	

Computer generated list of AC most likely to be available for deployment

1. AO315
2. AO316
3. AO317
4. AO300
5. AO304
6. AO301
7. AO302
8. AO303
9. AO305

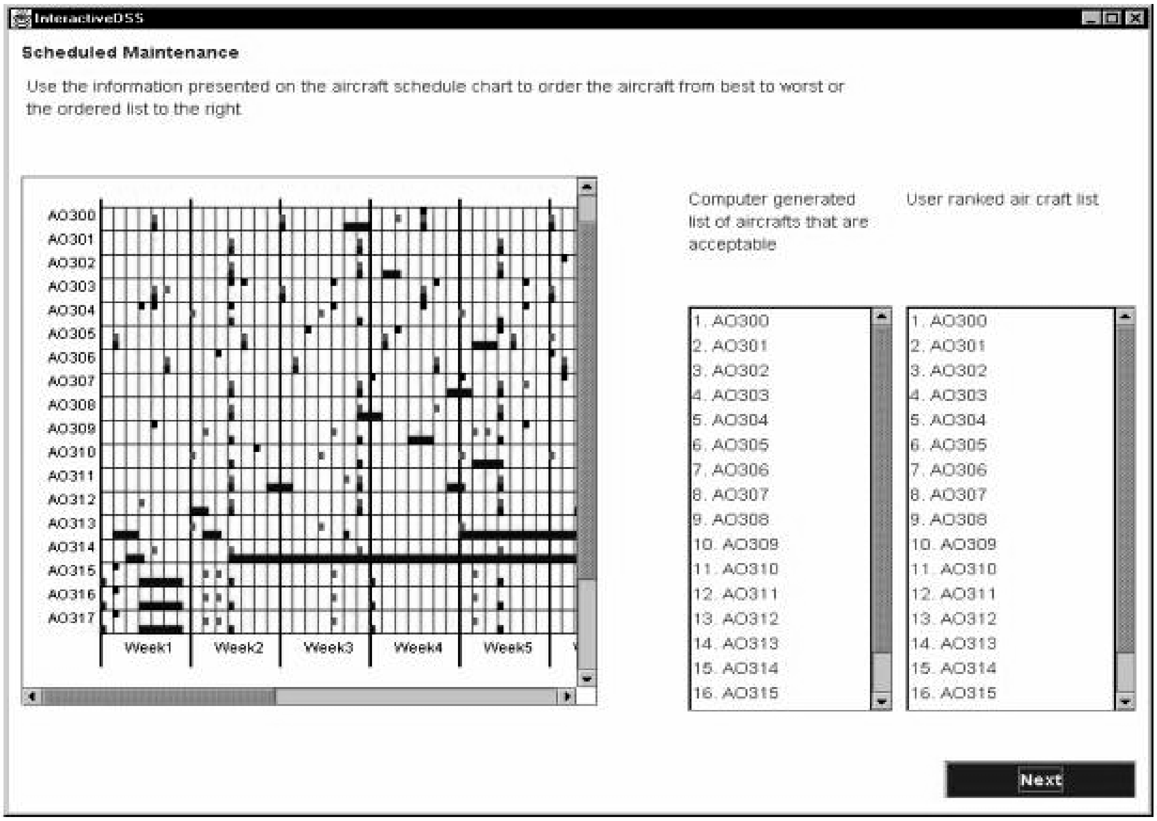
Human generated list of AC most likely to be available for deployment

Computer generated list of AC least likely to be available for deployment

1. AO312
2. AO313
3. AO314

Human generated list of AC least likely to be available for deployment

Figure 4. Screen shot of the first phase inspection task



Scheduled Maintenance

Use the information presented on the aircraft schedule chart to order the aircraft from best to worst or the ordered list to the right.

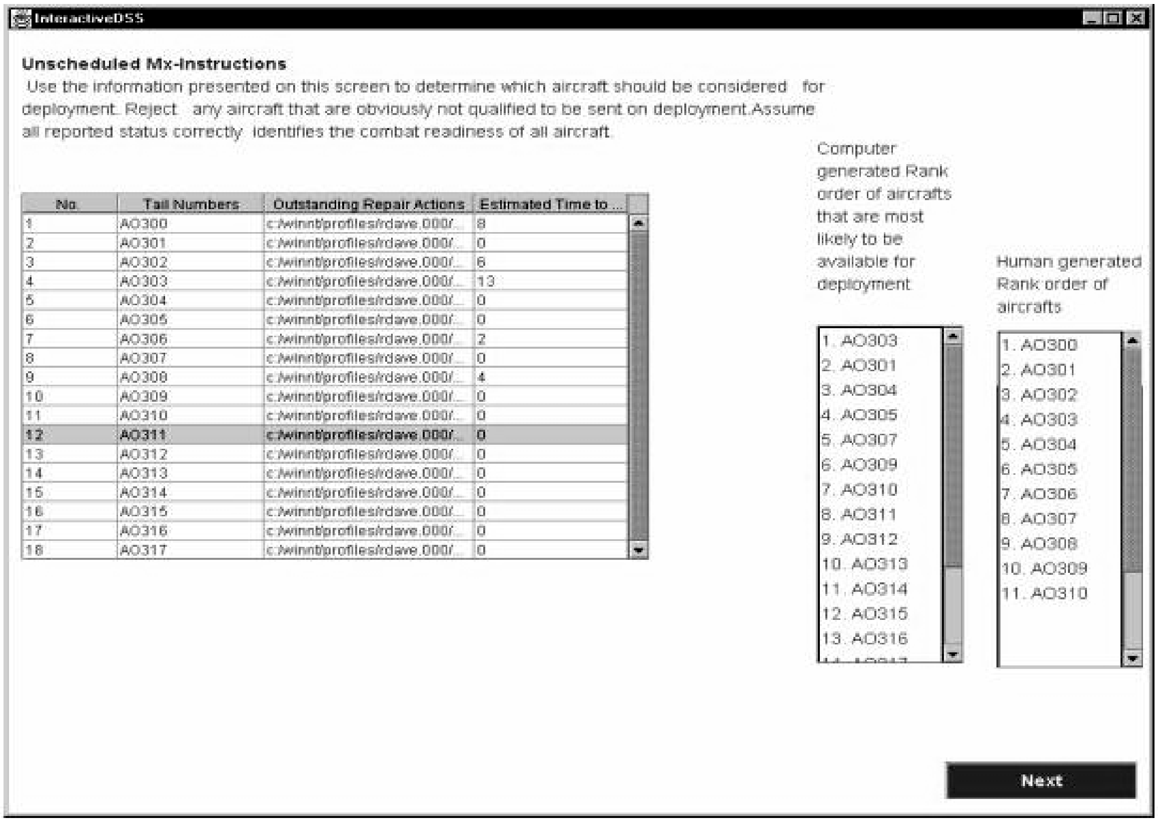
Computer generated list of aircrafts that are acceptable

1. AO300
2. AO301
3. AO302
4. AO303
5. AO304
6. AO305
7. AO306
8. AO307
9. AO308
10. AO309
11. AO310
12. AO311
13. AO312
14. AO313
15. AO314
16. AO315

User ranked air craft list

1. AO300
2. AO301
3. AO302
4. AO303
5. AO304
6. AO305
7. AO306
8. AO307
9. AO308
10. AO309
11. AO310
12. AO311
13. AO312
14. AO313
15. AO314
16. AO315

Figure 5. Screen shot of the scheduled maintenance task



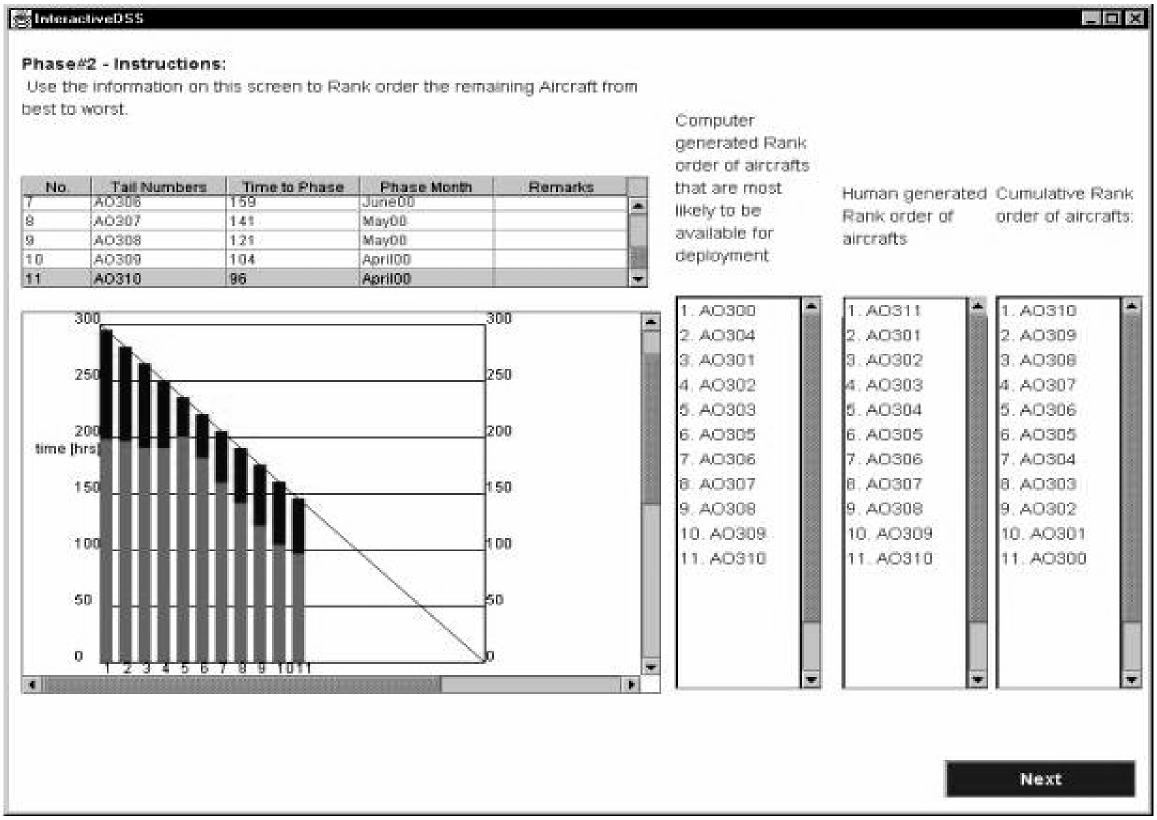
Unscheduled Mx-Instructions

Use the information presented on this screen to determine which aircraft should be considered for deployment. Reject any aircraft that are obviously not qualified to be sent on deployment.Assume all reported status correctly identifies the combat readiness of all aircraft.

No.	Tail Numbers	Outstanding Repair Actions	Estimated Time to ...
1	AO300	c:/winnt/profiles/rdave.000/...	8
2	AO301	c:/winnt/profiles/rdave.000/...	0
3	AO302	c:/winnt/profiles/rdave.000/...	6
4	AO303	c:/winnt/profiles/rdave.000/...	13
5	AO304	c:/winnt/profiles/rdave.000/...	0
6	AO305	c:/winnt/profiles/rdave.000/...	0
7	AO306	c:/winnt/profiles/rdave.000/...	2
8	AO307	c:/winnt/profiles/rdave.000/...	0
9	AO308	c:/winnt/profiles/rdave.000/...	4
10	AO309	c:/winnt/profiles/rdave.000/...	0
11	AO310	c:/winnt/profiles/rdave.000/...	0
12	AO311	c:/winnt/profiles/rdave.000/...	0
13	AO312	c:/winnt/profiles/rdave.000/...	0
14	AO313	c:/winnt/profiles/rdave.000/...	0
15	AO314	c:/winnt/profiles/rdave.000/...	0
16	AO315	c:/winnt/profiles/rdave.000/...	0
17	AO316	c:/winnt/profiles/rdave.000/...	0
18	AO317	c:/winnt/profiles/rdave.000/...	0

Computer generated Rank order of aircrafts that are most likely to be available for deployment	Human generated Rank order of aircrafts
1. AO303	1. AO300
2. AO301	2. AO301
3. AO304	3. AO302
4. AO305	4. AO303
5. AO307	5. AO304
6. AO309	6. AO305
7. AO310	7. AO306
8. AO311	8. AO307
9. AO312	9. AO308
10. AO313	10. AO309
11. AO314	11. AO310
12. AO315	
13. AO316	

Figure 6. Screen shot of the unscheduled maintenance task



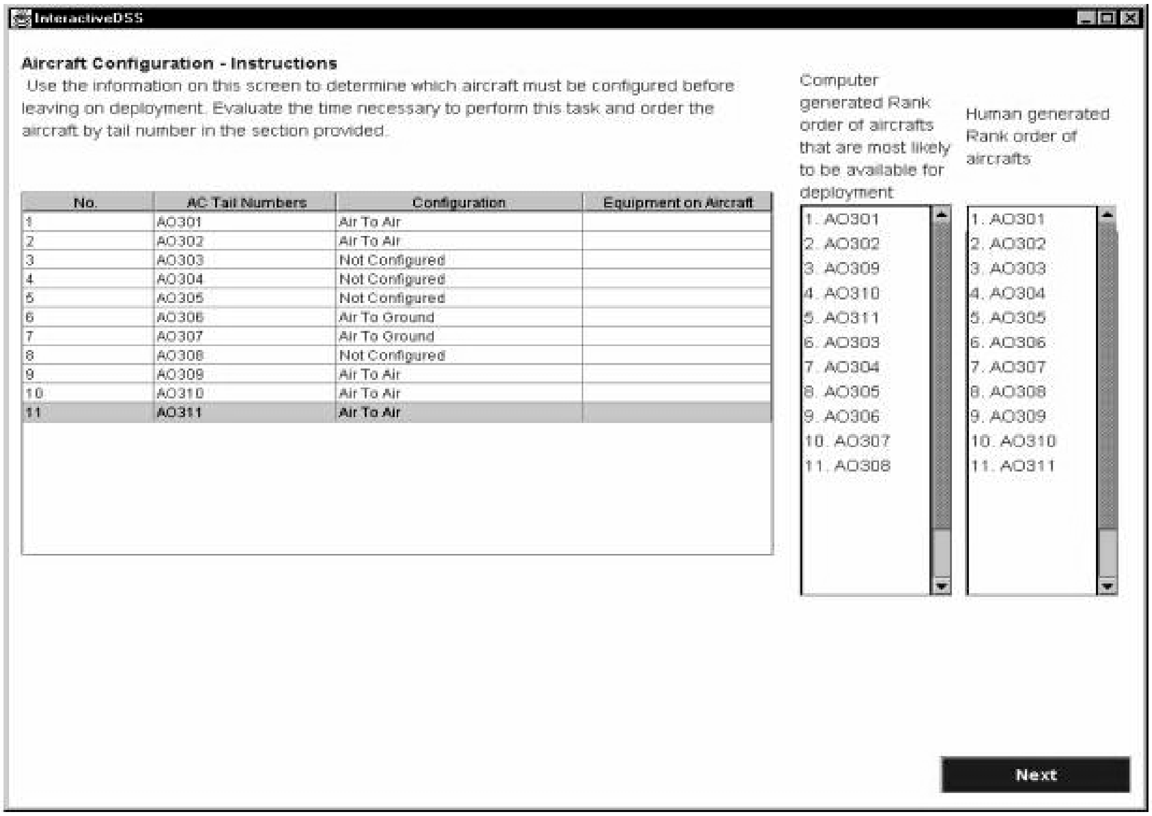
Phase#2 - Instructions:

Use the information on this screen to Rank order the remaining Aircraft from best to worst.

No.	Tail Numbers	Time to Phase	Phase Month	Remarks
7	AO306	159	June00	
8	AO307	141	May00	
9	AO308	121	May00	
10	AO309	104	April00	
11	AO310	96	April00	

Computer generated Rank order of aircrafts that are most likely to be available for deployment	Human generated Rank order of aircrafts	Cumulative Rank order of aircrafts:
1. AO300	1. AO311	1. AO310
2. AO304	2. AO301	2. AO309
3. AO301	3. AO302	3. AO308
4. AO302	4. AO303	4. AO307
5. AO303	5. AO304	5. AO306
6. AO305	6. AO305	6. AO305
7. AO306	7. AO306	7. AO304
8. AO307	8. AO307	8. AO303
9. AO308	9. AO308	9. AO302
10. AO309	10. AO309	10. AO301
11. AO310	11. AO310	11. AO300

Figure 7. Screen shot of the second phase inspection task



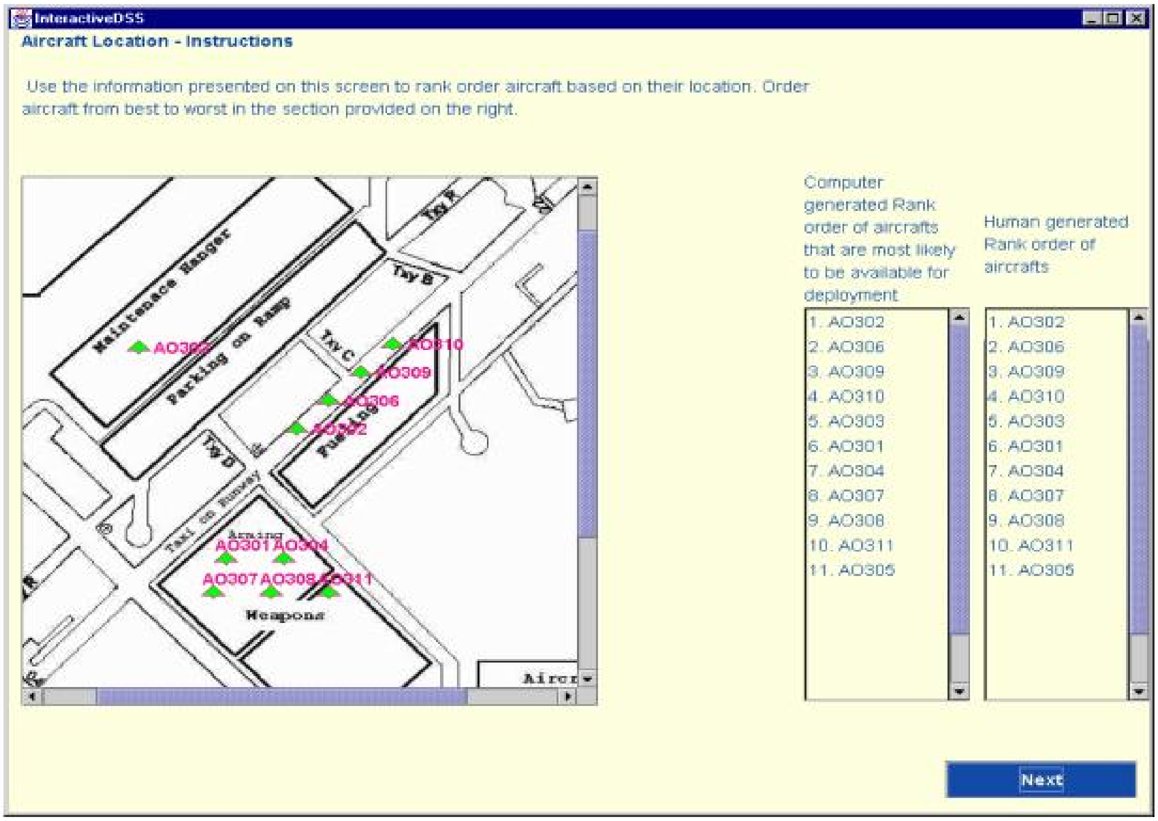
Aircraft Configuration - Instructions

Use the information on this screen to determine which aircraft must be configured before leaving on deployment. Evaluate the time necessary to perform this task and order the aircraft by tail number in the section provided.

No.	AC Tail Numbers	Configuration	Equipment on Aircraft
1	AO301	Air To Air	
2	AO302	Air To Air	
3	AO303	Not Configured	
4	AO304	Not Configured	
5	AO305	Not Configured	
6	AO306	Air To Ground	
7	AO307	Air To Ground	
8	AO308	Not Configured	
9	AO309	Air To Air	
10	AO310	Air To Air	
11	AO311	Air To Air	

Computer generated Rank order of aircrafts that are most likely to be available for deployment	Human generated Rank order of aircrafts
1. AO301	1. AO301
2. AO302	2. AO302
3. AO309	3. AO303
4. AO310	4. AO304
5. AO311	5. AO305
6. AO303	6. AO306
7. AO304	7. AO307
8. AO305	8. AO308
9. AO306	9. AO309
10. AO307	10. AO310
11. AO308	11. AO311

Figure 8. Screen shot of the aircraft configuration task

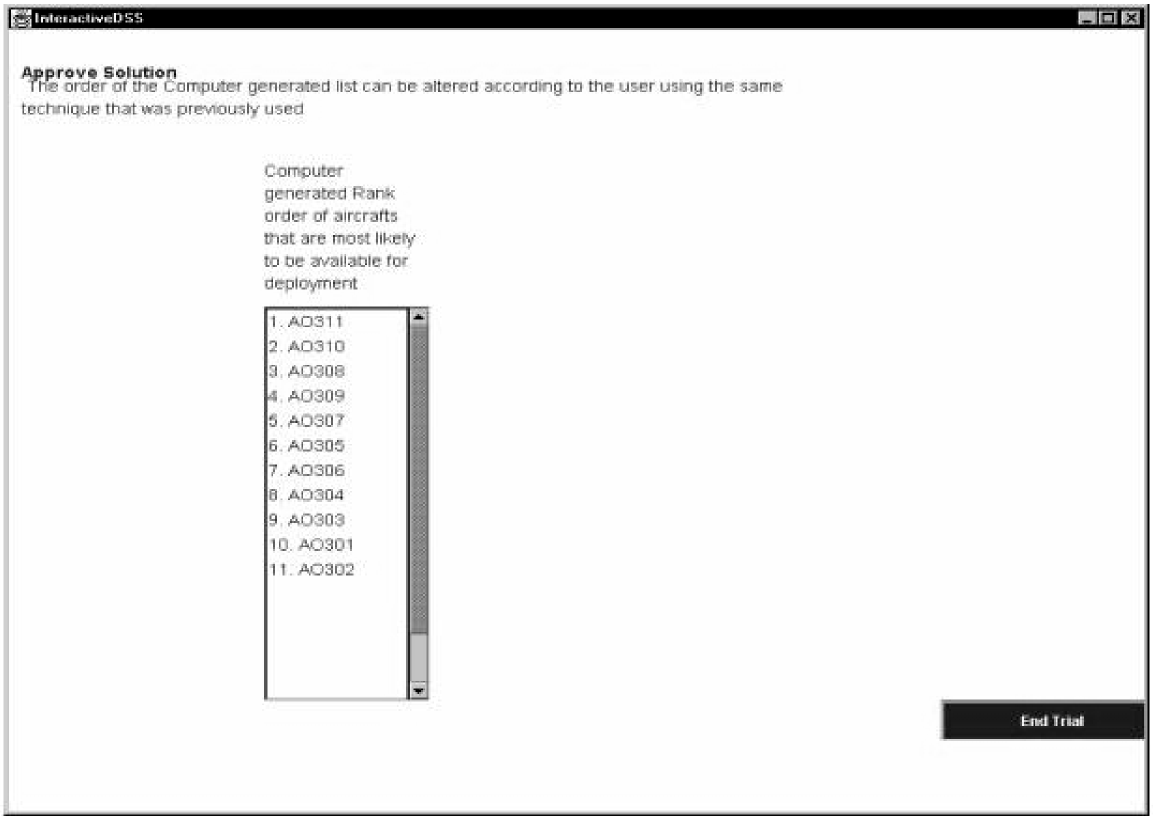


Aircraft Location - Instructions

Use the information presented on this screen to rank order aircraft based on their location. Order aircraft from best to worst in the section provided on the right.

Computer generated Rank order of aircrafts that are most likely to be available for deployment	Human generated Rank order of aircrafts
1. AO302	1. AO302
2. AO306	2. AO306
3. AO309	3. AO309
4. AO310	4. AO310
5. AO303	5. AO303
6. AO301	6. AO301
7. AO304	7. AO304
8. AO307	8. AO307
9. AO308	9. AO308
10. AO311	10. AO311
11. AO305	11. AO305

Figure 9. Screen shot of the aircraft location task



Approve Solution

The order of the Computer generated list can be altered according to the user using the same technique that was previously used

Computer generated Rank order of aircrafts that are most likely to be available for deployment

1. AO311
2. AO310
3. AO308
4. AO309
5. AO307
6. AO305
7. AO306
8. AO304
9. AO303
10. AO301
11. AO302

Figure 10. Approve solution screen

Aircraft with a longer time-to-phase inspection were generally considered better than those aircraft with less time due before major inspection. A second computer-generated list was provided on this screen representing the cumulative rank-ordering of available aircraft. Previous to this screen, cumulative progress was only identified by inclusion of the aircraft for consideration. At this stage, two screens (scheduled and unscheduled maintenance) of rank-ordered data were available to construct the cumulative rank-ordering of aircraft. Displaying cumulative feedback of on-going processes fulfilled the progress decision requirement for users to be cognizant of advancing solutions.

The final two subtasks, aircraft configuration and aircraft location, were evaluated in the next two screens; see Figures 8 and 9. Aircraft configuration and location data were evaluated to determine which aircraft required the most time and effort to make ready for departure. Locations of individual aircraft were shown in relation to other aircraft, facilities, and known hazards.

Figure 10 displays the cumulative list, where the user was allowed a final time to alter the solution set. Barring any further alteration, the entire task was then complete and the user was provided with a list of aircraft tail numbers rank-ordered from best to worst for choosing aircraft for the specified deployment. The top six aircraft were selected for deployment.

3.4 Evaluation

The subject pool for this experiment consisted of maintenance personnel from the 445th Air Force Reserve Squadron and Air Force Materiel Command familiar with elements of the selection task. Twelve subjects, all of whom were aircraft maintenance personnel, were asked to rank-order two distinct sets of aircraft for sortie using the IPO and IDSS tools. These personnel were workers who were familiar with the aircraft selection task in that they knew that the decision was made and who made it, and they were peripherally aware of the basics of the decision (novices). No subject had any physical impairment that would degrade performance with a color monitor, keyboard, or mouse. No subject was compensated for his or her time. Subjects consisted of one female and 11 male personnel.

Users were asked to perform the aircraft selection task within the context of a deployment-based scenario. Scenario instructions are illustrated in Figure 11.

> Scenario: You are the production superintendent of a maintenance squadron that provides maintenance support for 18, F-16 block 50 aircraft. You have been tasked by your supervisor to assess the current inventory of aircraft in your squadron and decide which six aircraft should be sent to support an AEF deployment to Aljaber, Kuwait. Upon arrival at the deployment destination the aircraft will be used to provide 100 hours of air-to-air coverage to on-going operations in the area.
> Use the program's step-by-step instructions and the information provided to select six aircraft from your squadron to support the AEF directive. These steps will guide you through an expert-derived process to find the best aircraft in the squadron to send on deployment. Any questions should be directed to the experimenter. You may practice as many times as necessary, until you feel comfortable enough to complete the task. When you are ready to attempt a timed trial, inform the experimenter and he will help you begin. Timing of the task begins when the first screen is displayed. Thank you for your participation.

Figure 11. Scenario-based instructions

The order of conditions was randomized, with six subjects utilizing the IDSS tool first, and the other six utilizing the IPO tool first. Additionally, a panel of three experts was asked to provide an ideal rank-ordering of aircraft for deployment. Experts were fully qualified aircraft production superintendents, each with over ten years' experience.

4. Results

The intersection between a subject's deployment set and the experts' deployment set (consisting of the top six rank-ordered aircraft) was calculated for each subject in each condition; see the example in Table 3. The intersections for the IDSS and IPO conditions were compared using a one-tailed *t*-test. The average intersection for the IDSS condition was significantly greater ($t_{11} = 1.45$, $p < 0.10$) than the average intersection for the IPO condition; see Figure 12. This indicates that decisions regarding sortie generation made using the IDSS more closely mimicked expert decisions than those made using IPO.

A *t*-test analysis of time-to-complete data indicated that the IDSS condition significantly improved timed performance over the IPO ($t_{11} = 1.50$, $p < 0.10$). Mean difference in time to complete the task was 391.5 seconds; see Figure 13.

Table 3. Sample results for one subject (intersecting data are shaded)

Dataset 1		Dataset 2	
Expert Order	Subject 1 Order (IPO)	Expert Order	Subject 1 Order (IDSS)
A0317	A0317	A0301	A0313
A0302	A0301	A0313	A0316
A0301	A0314	A0302	A0315
A0315	A0303	A0316	A0301
A0314	A0313	A0311	A0302
A0313	A0312	A0310	A0312
Intersection	4	Intersection	4

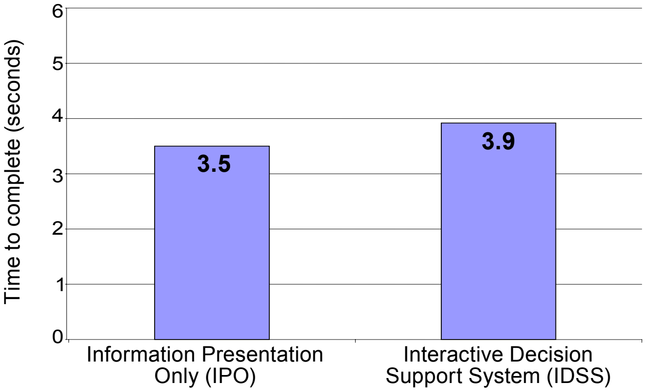


Figure 12. Average intersection between subjects' deployment sets and experts' deployment set for decision aid and information presentation alone

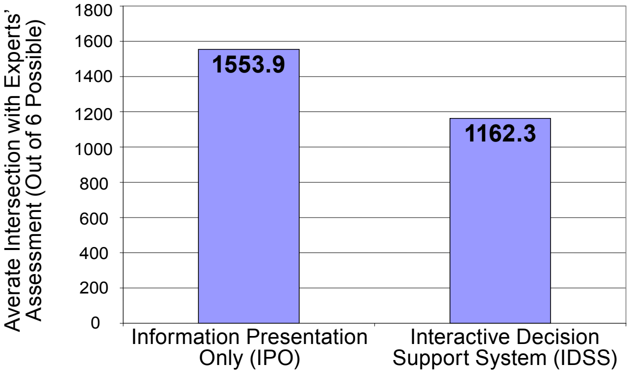


Figure 13. Average time to complete the task using the IPO and IDSS presentation modes

5. Discussion

The application of naturalistic decision theory to the military logistics arena provides a human-centered perspective that exploits the organic teleological processes inherent in human mental schemas. Providing information constrained to fit these processes allows decision makers more direct application of pertinent information to affect the generated solution within the context of the knowledge-based framework. The IDSS developed in this study provides formalization of the expert decision makers' natural choice strategies to evaluate decisions based on compatibility and profitability, adoption, or progression; IDSS abbreviates the decision process, thereby reducing internal complexity, confusion, and overall decision time.

Use of image theory to identify decision activity greatly increased the level of detail and understanding of the decision process of production superintendents. Standard methods for identifying decision subtasks did not necessarily direct the method in which those tasks were incorporated into the DSS. Uncovering the image states of the subject-matter experts led to the acquisition of their decision strategies. These decision strategies, once identified, not only changed the order of presentation, but highlighted significant structural changes to the algorithms used in providing computer-aided suggestions to the user.

Results indicate that the time taken to make decisions is significantly less for this IDSS when compared to an IPO mode. Additionally, decisions regarding which planes should be deployed were significantly closer to expert decisions when the DSS was used.

The U.S. Air Force is shifting toward expeditionary operations, smaller forces, and more frequent deployments. Fewer experts are available to solve the increasing number of complex problems; hence, the decision making is taking place at lower levels of management than previously experienced. Additionally, the personnel have to make quicker, more accurate decisions. The decision support tool developed and analyzed in this study allows personnel to make faster decisions and brings them significantly closer to the level of experts.

6. Conclusion

Decision support needs for supervisors in logistics have been largely deferred in favor of high visibility management where the informational needs are more globally oriented, integrating vast amounts of data combined with uncertainty and a heterogeneous perspective [7]. Lower levels of management have different needs for decision support than upper level managers but remain just as dependent on computer information and computer support. Large problem spaces, even at the squadron level, complicate the thorough examination of data and hinder the process of shortfall identification, repeat or recurring problem analysis, and determination of system patterns on which quality decision making depends. Impactful decision support incorporating satisficing heuristics [11] may enable a more direct and immediate application of supervision on the production of aircraft sortie generation and on overall squadron production.

This research project represents a practical contribution to information systems research by outlining a methodology for creating DSSs in complex logistics planning. Contributions include uncovering decision support needs for the organizational strata of frontline supervisors, applying naturalistic decision theory to the logistics arena, and defining a level of interaction between the decision maker and the DSS that accommodates subgoal variation while maintaining the structure of the knowledge-based framework. By defining a level of interaction between the user and the DSS, image states and goal-directed behavior inherent to logistics organizations can be applied to the decision process while taking advantage of computer processing speed to identify patterns, process heuristics, and make computations.

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