ARMY RESEARCH LABORATORY

Using Simulation Models to Analyze the Effects of Crew Size and Crew Fatigue on the Control of Tactical Unmanned Aerial Vehicles (TUAVs)

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under contract

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Abstract

This report describes a study conducted by Micro Analysis and Design, Inc., for the U.S. Army Research Laboratory (ARL). One area of research examined by ARL was the staffing required to operate tactical unmanned aerial vehicles (TUAVs). The primary objective of the study was to use simulation modeling to analyze how fatigue, crew size, and rotation schedule affect operator workload and performance during the control of a TUAV. Computer simulation models were developed with the Micro Saint Discrete Event Simulation software to simulate the tasks that operators perform when controlling a TUAV. These models, which contain system-specific attributes of the Shadow 200[1] TUAV, included a fatigue function to predict performance effects for day and night missions. Subject matter experts (SMEs) provided the list of tasks involved in controlling a TUAV (during normal operations and emergencies), the order of these tasks, and the visual, auditory, cognitive, and psychomotor workload values associated with each task. Twelve different crew configurations were examined for the tactical operations center (TOC) and the launch and recovery station (LRS), which ranged in size from 8 to 15 crew members. The conclusions from executing the models and interviewing SMEs (during 12- and 18-hour missions) indicate that reducing the number of aerial vehicle operators (AVOs) and mission payload operators (MPOs) in the TOC can result in more aerial vehicle mishaps during emergencies, increased search time, and a decreased number of targets detected. For example, compared to six AVOs or MPOs in the TOC, the addition of two crew members resulted in only slight performance gains of a 6% increase in target detection and a 4% decrease in target search time. However, when the members of the crew were reduced to four AVOs or MPOs in the TOC, there was substantial performance loss (20% decrease in target detection and a 15% increase in target search time). The general conclusion is that a crew of 12 (TOC [two MCs and six AVOs or MPOs]; LRS [two MCs and two AVOs]) is the most efficient trade-off between performance and crew size. The implications of these findings for other possible crew configurations are discussed, along with plans for further analyses.

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[1] a mapping exercise that took place at Fort Huachuca in March 2000.

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USING SIMULATION MODELS TO ANALYZE THE EFFECTS OF CREW SIZE AND CREW FATIGUE ON THE CONTROL OF TACTICAL UNMANNED AERIAL VEHICLES (TUAVs)

1. Background

This report describes a study conducted by Micro Analysis and Design, Inc., for the U.S. Army Research Laboratory (ARL). One area of research examined at ARL is the staffing required to operate tactical unmanned aerial vehicle (TUAV) systems. TUAVs are intended to provide reconnaissance, surveillance, and target acquisition, as well as battle management and battle damage assessment information in a 50- (threshold) to 200- (objective) kilometer radius of action from a controlling ground control station. TUAVs are to be deployed worldwide and must be capable of penetrating and successfully operating within enemy air space during day and night missions and in adverse weather.

The primary objective of the study was to use simulation modeling to analyze how fatigue, crew size, and rotation schedule affected operator workload and performance during the control of a TUAV. A modeling tool such as Micro Saint allows analysts to investigate a wide variety of possible future missions during variable fatigue and circadian conditions. The results of this study will be used by ARL scientists to make preliminary staffing recommendations for TUAV operational testing. The importance of setting realistic crew sizes, based on actual operational contingencies, makes the use of soldier performance modeling particularly cost effective. Data from future field experiments can be incorporated into the basic modeling environment to validate and extend the preliminary results.

The following lists the four tasks that represent the technical objectives of the project:

1. Develop computer simulation models that will address the impact of crew size and task allocation on the control of a TUAV. This will include the use of task network modeling to examine the effects of varying shift length, rotation schedule, type of scenario, and task allocation on system performance time and workload.

2. Review the literature and ongoing projects to develop an algorithm to address the effects of fatigue on performance. Consider the joint impact of fatigue and circadian rhythm. Apply this algorithm to the simulation model. Evaluate the results to determine whether various shift lengths, rotation schedules, or task allocation strategies can be used to reduce the impact of these stressors.

3. Perform on-site data collection and support. Collect data with experienced TUAV subject matter experts (SMEs) to establish crew schedules, rotations, workload values, and fatigue effects.

4. Modify the model so that it represents the Shadow 200[1] TUAV. Exercise the model so that unique aspects of the platform can be studied. Exercising the model will include the required and objective operating tempo for the specific platform chosen to include mission capabilities for these requirements as defined by the operational requirements document.

Computer models were developed with Micro Saint to simulate the tasks that operators perform when controlling a TUAV. These models, which contained system-specific attributes of the Shadow 200 TUAV (AAI Corporation, 2000), included a fatigue function to predict performance effects for day and night missions. SMEs provided the list of tasks involved in controlling a TUAV (during normal operations and emergencies), the order of these tasks, and the visual, auditory, cognitive, and psychomotor workload values associated with each task. The TUAV models were developed to simulate 18-hour missions with 2-, 3-, 4-, and 6-hour rotation schedules and were re-run to simulate two 12-hour missions. Different weather, terrain, search, and emergency conditions were also programmed into the models.

2. Methods

2.1 SME Participants

Eighteen SMEs from Fort Huachuca, Arizona, provided (a) a list of tasks involved in controlling a TUAV (during normal operations and emergencies), (b) the order of these tasks, (c) the visual, auditory, cognitive, and psychomotor workload values associated with each task, (d) the types of emergencies that can occur during missions, and (e) the probabilities of mishaps occurring during emergencies when soldiers are fatigued. These data were obtained through questionnaires and informal interviews. The SMEs, who were made available to this project by the Training and Doctrine Systems Manager (TSM) for TUAVs, represented the best available civilian and military expertise available in the Army. At the time the interviews were conducted, Fort Huachuca was the national training school for all Department of Defense unmanned aerial vehicle (UAV) operators. In addition, these data were supplemented with information obtained from the operational model summary and mission profile for the Shadow 200 and from previous TUAV models and studies (Barnes, Knapp, Tillman, Walters, & Velicki, 2000).

2.2 Modeling

Simulation models developed on computers can be used to simulate operator and crew performance to fill gaps in knowledge and to develop regulatory guidance. Depending on the parameters of performance modeled (e.g., objective performance, cognitive performance, etc.), these simulations often permit interaction between operators in the models and the simulation

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[1] a mapping exercise that took place at Fort Huachuca in March 2000.

context (e.g., the command center), between operators and objects (e.g. procedures), and between operators (i.e., intra-crew activities).

The objects and operators modeled in such simulations have parameters that define how they function in the simulation. Consider, for example, a simulation of an operator's performance in following procedures to achieve a mission objective. The model of the operator can include such parameters as the operator's previous experience and familiarity with the operation, the accessibility of the procedures both physically and conceptually, the number of tasks and steps, the relative complexity of the task, and the likelihood of error. Parameters of the procedure(s) can be modeled to predict how qualitative aspects of the procedures (e.g., readability, complexity, and format) may affect operator performance. Parameters of the procedures can also be modeled to predict how relevant aspects of the command center (e.g., location, operating mode, and condition complexity) affect operator performance.

Because models are run on computer systems, there are no practical limitations on the number of trials or simulation runs that can be made. Models can be programmed to include provisions for user-input values for parameters and rules (e.g., number of operators, type of interface, and time of day), thereby allowing different performance conditions to be simulated. This permits the investigation of possible changes in operator or crew performance that can occur in response to changes in other aspects of the simulated context and objects. Changes include the timing of events, variation of performance shaping factors (e.g., stress, time available, quality of procedures, and crew interaction quality) and the availability of crew members (i.e., whether normally staffed or minimally staffed). Because models do not have the problems that researchers have in finding available crews to be research subjects and because models allow users to vary parameters, simulations represent a resource for generating information about operator and crew performance during statistically high power conditions.

2.3 Discrete Event Simulation With Micro Saint

Discrete event simulations (DES) use a computer model to describe a process that can be expressed as a sequence of events, each with a distinct beginning and end. Events can be any part of the process such as scheduled activities or tasks that represent the flow of the process. The tasks are displayed schematically on a diagram called the task network diagram, which is the basis of the model.

Micro Saint is a simulation software package for constructing models that simulate real-life processes. These models can be relatively simple or complex. One can build a simple, functional model by creating a network diagram and entering task-timing information for each task in the network. More complex models can be built, which include dynamically changing variables, probabilistic and tactical branching logic, conditional task execution, and extensive model data collection. One can specify all these by choosing menu commands or by providing expressions for Micro Saint to execute during specific circumstances.

Whether the model is simple or complex, the process of executing a Micro Saint model and generating statistics and graphs from the collected data is mostly automatic. In addition, the results files can be opened in spreadsheets or statistical packages for further analysis. For questions and a more detailed understanding of Micro Saint, refer to the Micro Saint User's Manual (Micro Analysis and Design, 1999).

2.4 Fatigue

The impact of fatigue induced by sleep deprivation or poor sleep has always played an important role on the effectiveness of troops (Belenky, Kreuger, Bailking, Headley, & Solick, 1987). The impact is not lessened by the increase in night operations and high intensity around-the-clock operations expected in near future threats. Fatigue is arguably one of the most persistent threats to mission success during sustained or continuous operations. Much is known about the effects that fatigue has on performance. The effects have been consistently demonstrated in multiple sleep deprivation studies. For example, cognitive capacity can decline about 60% after two nights of sleep deprivation (Angus & Heselgrave, 1985). Decreases in asymptotic performance between 10% and 20% are reported during an extended performance of less than 24 hours' duration (Benline, French, & Wing, 1997). Recently, Dawson and Reid (1997) proposed that performance after 21 hours of sleep deprivation was comparable with performance degradation following legal levels (0.1%) of intoxication.

The fatigue algorithm used for this project predicts human response capability for tasks over an extended period of sleep deprivation (as many as 52 hours). The main focus of the algorithm is the interaction of sleep deprivation (i.e., fatigue) with circadian disruption on performance. It is based on data collected at Brooks Air Force Base, San Antonio, Texas, with pilots as subjects during a sleep deprivation study. More than 15 different tasks were used in the study, and the subjects cycled through each about once every 1.5 hours. The fatigue algorithm is based on one of those tasks: the Maniken task of the attention-switching task. This task was selected because it is a complex visual task; it required the subject to pay attention to a signal on the screen while he performed one of two tasks to know when to switch to and from one task to another. It is an intellectually challenging test that has consistently proved sensitive to fatigue and other stressors in a number of experiments. It is similar to the kinds of visual and performance demands placed on TUAV operators.

The Brooks Air Force data were plotted as shown in Figure 1. A cosine curve was fit to the data to unmask the circadian features of performance (Naitoh, Englund, & Ryman, 1985). This involved a complex demodulation function to separate the linear aspects of the data. The remainder is the circadian function that allows oscillating performance levels to be reliably predicted for extended periods of time over several days (Redmond, Sing, & Hegge, 1982). The algorithm accounts for a significant amount of the variance; although most of the variance is linear (0.89%), the cosine fit provides an important oscillating function.

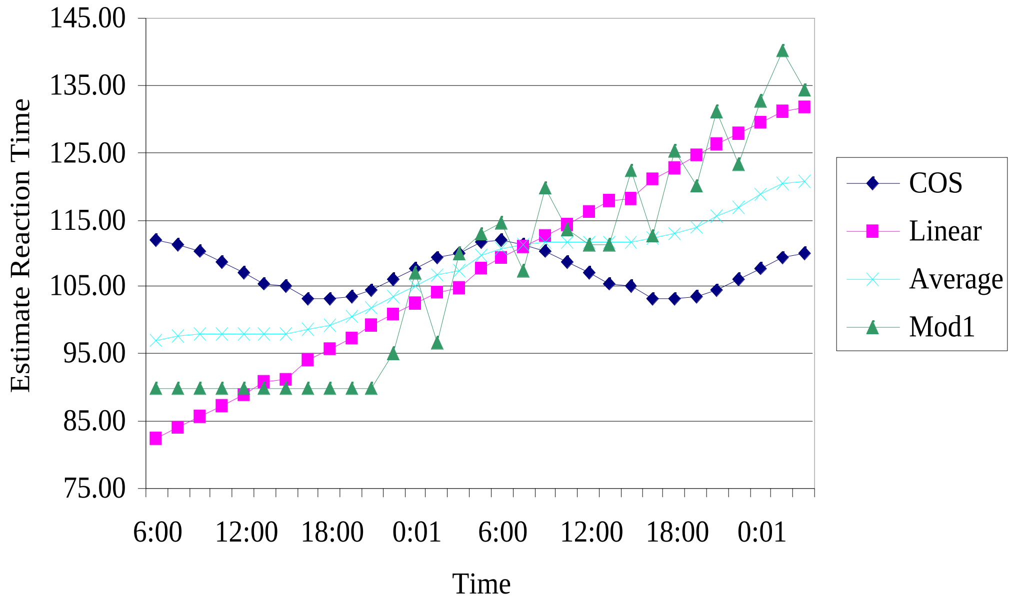

Figure 1. The Maniken Data Used to Make the Algorithm (Mod 1), the Cosine Function Data (COS), the Linear Function Data (linear), and the Predicted Response Time Capability (average) Expressed as Percent Baseline Response Time.

In the model, crew size and rotation schedule affect the soldiers' sleep and rest cycles, which in turn affect their fatigue, circadian rhythms, workload, and performance. As fatigue and workload increase, target search time, target detection rate, and human errors increase, thus increasing the likelihood of TUAV mishaps. Also, the more time an operator spends on a task (vigilance) such as monitoring, the greater the decrease in his or her performance over time. In the model, the times to perform the tasks were generated from SMEs. These values were then adjusted by the fatigue algorithm, the time into the scenario, and vigilance decrements based on how much time was spent monitoring (Deaton & Parasuraman, 1988; Molloy & Parasuraman, 1996). Because soldiers were limited to 12-hour duties, fatigue played a minor role in affecting task performance. Instead, vigilance and workload had the most effect on target search time and the number of targets detected.

2.5 Assumptions

Appendix A provides a sample of some of the task networks in the model. The model simulates the tactical operations center (TOC) and the launch/recover station (LRS) (mission commander [MC], aerial vehicle operator [AVO], and mission payload operator [MPO] duties), and the following functions: launch, transfers, recovery of the TUAVs, mission support, emplacement, displacement, emergencies, mishaps, and basic duties of the maintenance crew during emplacement. The model does *not* simulate the platoon sergeant, the platoon leader, or the complete maintenance duties. Parameters and assumptions about the Shadow 200 and the corresponding mission profiles were obtained from the operational model summary and mission profile for the Shadow 200 and the mapping exercise that took place at Fort Huachuca. These parameters were used to help further define the structure of the model.

The TUAV model simulates 12- and 18-hour missions (over a 24-hour period) during 15 different conditions for three consecutive days. During missions, there are times when two aerial vehicles (AV) are in flight: when one AV is observing the targets and one AV is flying to assume control of the search. Although, the workload scores were affected by the overlap when two AVs were in flight simultaneously, the target detection scores were not adjusted for the overlap period. Soldiers will work 2-, 3-, 4-, or 6-hour rotation schedules. During times when they are not in the shelter or moving, soldiers may be resting, eating, performing guard duty, or mission planning. However, the model does not simulate specifically what the soldiers are doing during these periods.

The models simulate one move (jump) per day for the TOC and one move every other day for the LRS. Each move consists of a half-hour “break-down,” half-hour move, and a 1-hour setup. The time to the destinations will not vary. A TUAV spends 5 hours of simulation time in the air: 4 hours of surveillance and 1 hour to fly to and from its destination. The model simulates three TUAVs and one floating TUAV. TUAVs are not flown in snow, thunderstorms, high winds, or heavy rain conditions. The output produced by the model includes performance times and target detection rates and AV mishaps during each of the simulated conditions.

2.6 Crew Configurations

The following crew configurations for the TOC and LRS were simulated in the model. Table 1 lists the 12 different combinations that these configurations produced.

TOC	LRS
2 MCs and 4 AVOs/MPOs	0 MCs and 2 AVOs
2 MCs and 6 AVOs/MPOs	1 MC and 2 AVOs
2 MCs and 8 AVOs/MPOs	2 MCs and 2 AVOs
	2 MCs and 3 AVOs

Appendix B lists the rotation schedules used in the model for each crew configuration. Crew size determines the rotation schedule because of the 12-hour limit that is placed on the duty shift of soldiers.

Table 1. Crew Configurations for Soldiers With a Military Occupational Specialty of 96U

	Crew for each 12-hour shift	
Total crew size	TOC	LRS
8	1 MC, 2 AVOs/MPOs	0 MCs, 1 AVO
9	1 MC, 2 AVOs/MPOs	0.5 MC[a], 1 AVO
10	1 MC, 2 AVOs/MPOs	1 MC, 1 AVO
10	1 MC, 3 AVOs/MPOs	0 MCs, 1 AVO
11	1 MC, 2 AVOs/MPOs	1 MC, 1.5 AVOs[b]
11	1 MC, 3 AVOs/MPOs	0.5 MC[a], 1 AVO
12	1 MC, 3 AVOs/MPOs	1 MC, 1 AVO
12	1 MC, 4 AVOs/MPOs	0 MCs, 1 AVO
13	1 MC, 3 AVOs/MPOs	1 MC, 1.5 AVOs[b]
13	1 MC, 4 AVOs/MPOs	0.5 MC[a], 1 AVO
14	1 MC, 4 AVOs/MPOs	1 MC, 1 AVO
15	1 MC, 4 AVOs/MPOs	1 MC, 1.5 AVOs[b]

[a] There is actually only one MC available for this configuration.
[b] There are actually a total of three AVOs for this configuration.

2.7 Conditions

The following list describes different conditions that can affect a TUAV mission. These conditions are categorized into the type of search being performed, emergencies that can occur, weather conditions, and terrain. Different conditions can affect the rates of target detection and time to perform a task and fly the TUAV. Emergencies cause operators to perform specific tasks that reduce search time.

- The type of search being performed: area search, person search, airfield, tanks, building, road search, bridge, missile site, command post, air defense artillery (ADA), check points, battle damage assessment (BDA) on surface-to-air missile (SAM), artillery search.
- Emergencies that can occur: icing, generator failure, signal degrada-tion or intermittent link loss, payload failure, AVO or MPO console failure, global positioning satellite (GPS) failure.
- Weather: humidity, sunny, gusty winds, crosswinds, flat clouds, ragged clouds.
- Terrain: high vegetation, desert (sand), high desert, city, town or village.

2.8 Workload

Workload values for each task in the model were obtained from SMEs at Fort Huachuca. Workload was estimated from a scale developed by McCracken and Aldrich (1984) and later enhanced by Szabo and Aldrich (1987) and Aldrich, Szabo, and Bierbaum (1989). Their scale was originally developed to provide a workload estimate compatible with Wickens (1984), in which mental workload is viewed as consisting of multiple cognitive resources. The scale was originally designed for use in discrete task network tools. Four resources or components are typically used in mental workload models: visual, auditory, cognitive, and psychomotor. Typically, the visual and auditory components refer to the information processing of stimuli surrounding a mission task event. The cognitive component consists of the information processing synthesis. The psychomotor component is directed by the physical responses required of a mission event.

Workload theory is based on the idea that every task a human performs requires some work. Usually, a task is composed of several different types of work, such as visual or cognitive. For example, consider a task such as steering a car. This task will have some visual work (watch where you are going), some cognitive work (decide if you are turning enough), and some psychomotor work (rotate the steering wheel). The workload theory implemented in this effort assigns values representing the amount of effort that must be expended in each channel in order to perform the task. The scale for each component ranges from 0 (very low workload) to 7 (very high workload).

This theory also hypothesizes that if you are doing two tasks at once, the workload levels are additive within channels, across tasks. For example, if you were doing two tasks at once, one with a psychomotor load of 2.6 and one with a psychomotor load of 4.6, then a psychomotor score of 7.2 (2.6 + 4.6) would be recorded for the time that the two tasks were being performed together. A criterion of overload was set at 7 for each channel and 28 for a particular task load. These settings were derived from experience with rotor aircraft and they reflect an increased potential for accidents¾a finding that agrees with experimental results during UAV missions as well (Barnes & Matz, 1998).

2.9 Missions

The model simulates five TUAV launches per day for an 18-hour mission, regardless of crew rotation schedule. For each launch, three different types of target searches were performed. This resulted in 15 different types of searches per day. These missions were repeated every day for 3 days (72 hours) in the model for each crew rotation schedule. Rather than simulate every combination of the four conditions described earlier, Table 2 lists the 15 that were chosen, based on SMEs’ opinion of the importance of the predicted results.

To determine the amount of power necessary to detect a difference in experimental conditions, a power analysis table within Keppel (1991) was referenced. With an alpha level of .05 and a small effect size (.01), it was necessary to obtain 354 data points per cell to obtain 90% power. Thus, the model was run 400 times for each rotation schedule to obtain slightly more than 90% power.

Table 2. Conditions (scenarios) Simulated in the Model

Search	Emergency	Weather	Terrain
Area search	Engine failure	Sunny/high winds	Desert
Personnel search	Intermittent link loss	Sunny	City
Airfield search	Payload failure	Ragged clouds	High vegetation
Tank search	AVO/MPO console fails	Cross winds	High desert
Building search	GPS failure	Hazy	City (2 square blocks)
Road search	AVO/MPO console fails	Gusty winds	Desert
Bridge search	Intermittent link loss	Low clouds, humid	Town
SCUD site	Payload failure	Hazy/foggy	High desert
Command post	AVO/MPO console fails	Rain	City
ADA check points	None	Gusty winds	High vegetation
BDA on SAM	None	Humid	Desert
Artillery search	None	Sunny	Desert
Area search	Icing	Snow on ground	Town
Tank search	AVO/MPO console fails	Clouds – flat	Desert
Building search	None	Scattered clouds	High vegetation

3. Results

An analysis of variance was performed on the model output to see how different crew sizes and fatigue affect the amount of time that operators spend searching for a target and the number of targets detected during a 72-hour period. Scores for the 2- and 3-hour rotation schedules were combined because they were not significantly different from each other and because they used the same number of crew members. The results showed a significant effect for crew size on the model output: (F(3,1396) = 12759.24; $p < 0.01$) and (F(3,1396) = 7379.29; $p < 0.05$), respectively. *Post hoc* analyses (Tukey's Honestly Significant Difference Test) revealed that decreasing the crew size results in an increase in the amount of time to detect a target (see Figure 2) and a decrease in the number of targets detected (see Figure 3). The only comparison that was significant ($p < 0.05$) was between the crew sizes of six and four. Decreasing the number of AVOs or MPOs in the TOC from eight to six resulted in a 4% increase in the time to search a target and a 6% decrease in the number of targets detected. Decreasing the number of AVOs or

MPOs in the TOC from six to four resulted in a 15% increase in the time to search a target and a 20% decrease in the number of targets detected.

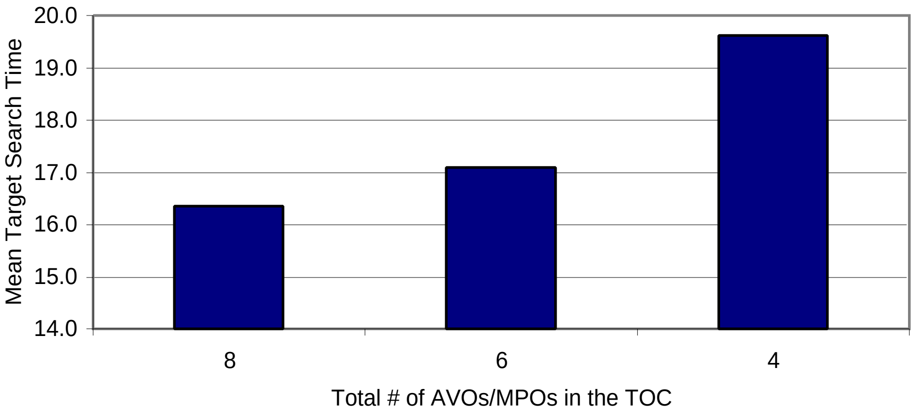

Figure 2. The Mean Target Search Time for Each Crew Size for an 18-hour Mission.

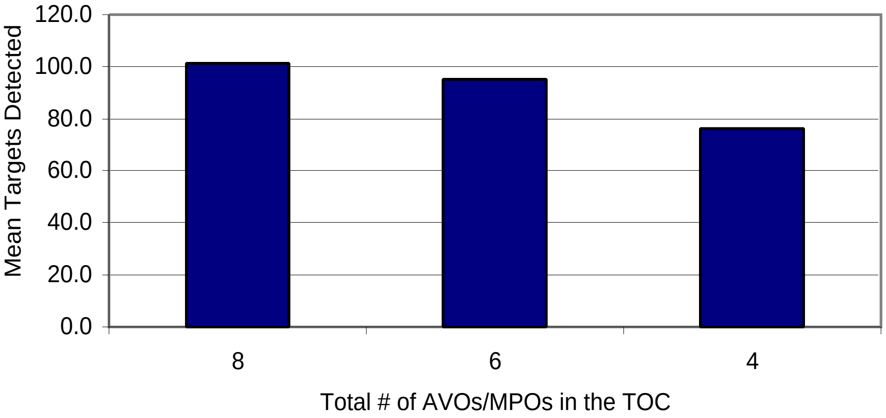

Figure 3. The Mean Number of Targets Detected for Each Crew Size for an 18-hour Mission.

Analysis of the SME data indicated that almost three times as many AV mishaps can occur when a crew is fatigued than when they are well rested (see Figure 4). These mishaps are related to a console failure, lost link, GPS failure, and/or degraded communications. We calculated the number of mishaps for the well-rested and fatigued conditions by multiplying the probability of an emergency occurring times the probability of making a mistake during the emergency times the probability of a mishap occurring if a mistake were made. The calculated values for each emergency were added together to produce the results in Figure 4.

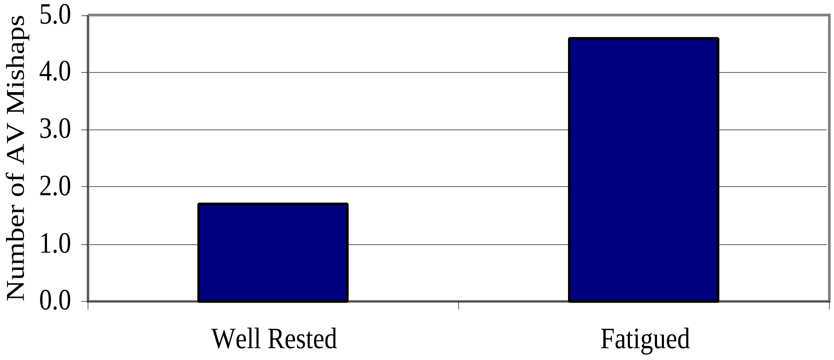

Figure 4. The Number of AV Mishaps per 1000 Missions When a Crew is Fatigued or Well Rested.

Analysis of the workload data produced by the model showed that when there was no MC in the LRS, the TOC MC was interrupted approximately 50% of the time with tasks that would have been performed by the LRS MC (see Figure 5). (A total workload value greater than 28 [threshold] indicates an overload on at least one or more workload channels [see the discussion section for the implications of exceeding this threshold].) For a 12-hour shift, this means that 6 hours of the TOC MC's time were spent performing the duties of the LRS MC. When there was one MC in the LRS, the TOC MC was interrupted approximately 20% (2.5 hours) of the time with tasks that would have normally been performed by the LRS MC (see Figure 6). Finally, analysis of the workload data showed that adding a third AVO to the LRS (compared to the baseline of two AVOs) did not affect the performance of a mission.

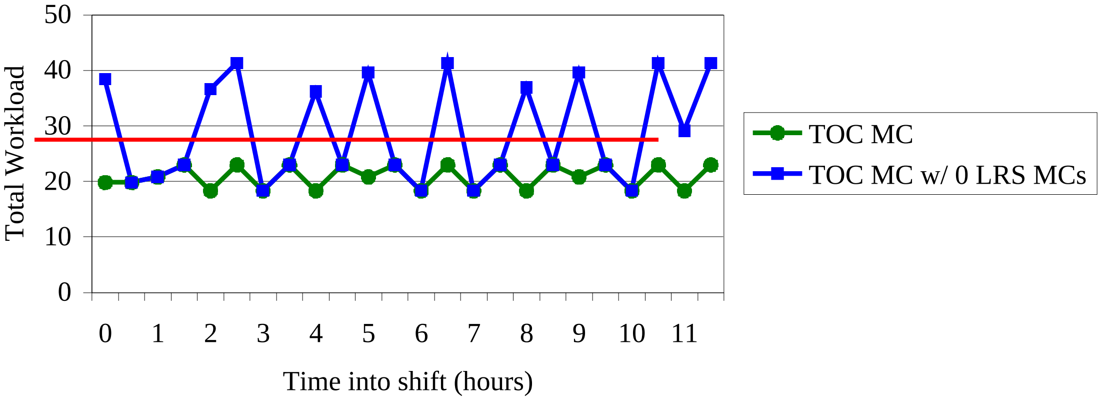

Figure 5. Workload Values for the TOC MC During a 12-hour shift With No MC or Two MCs in the LRS. (The red line is the overload threshold.)

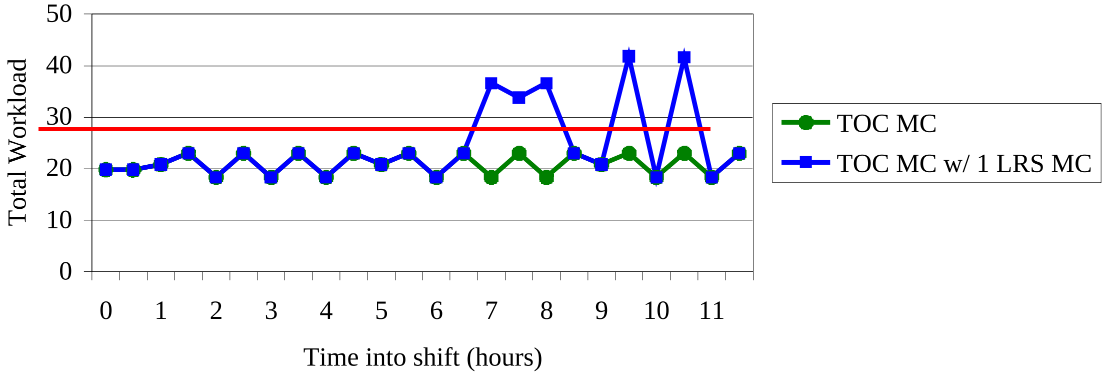

Figure 6. Workload Values for the TOC MC During a 12-hour shift With One or Two MCs in the LRS. (The red line is the overload threshold.)

3.1 Additional Modeling

The TUAV model was then adjusted to simulate two new mission profiles: a 12-hour mission with 1-hour gaps between flights and a 12-hour mission with no gaps between flights (see Appendix C for the mission profiles). Three AV launches were simulated per day rather than five (as were simulated with the 18-hour mission). All other parameters remained the same.

3.2 Additional Modeling Results

The same performance trends that were found with the 18-hour mission were also found with both 12-hour missions: reducing the number of AVOs or MPOs in the TOC resulted in an increase in the time to search for targets and a decrease in the number of targets detected. No performance differences were found between the 12-hour mission with 1-hour gaps (between flights) and the 12-hour mission with no gaps (between flights). Approximately 40% fewer targets were found during the 12-hour missions than during the 18-hour mission because of the difference in the number of AV launches per day. No differences in average target search times were found between the 12-hour missions and the 18-hour mission.

4. Discussion

Changes in military contingencies in the last decade have led to reduced funding for expensive field exercises and training. Consequently, planners have increasingly turned to modeling and simulation efforts for “war gaming” and to estimate the operational impact of new systems. Evaluating the human impact on complex systems has lagged and has resulted in a decrease in system outcome fidelity. Small, computer-derived network simulation models are ideal for these studies and can address a wide variety of human interface solutions and the effects of operator workload.

Computer models are frequently used to estimate theater losses attributable to nuclear, chemical, or biological events. However, other threats may be amenable to computer evaluation; such evaluation would enhance the realism of modeling or war-gaming exercises. Fatigue induced by sleep deprivation or by poor sleep has always played an important role in the effectiveness of troops. The impact is not lessened by the increase in night operations and high intensity, around-the-clock operations expected in near future threats.

ARL is concerned with the staffing required to operate TUAVs. The operational requirements of the TUAV operators may include extended duty days, reduced crew size, and varying shift schedules. These conditions are likely to reduce operator effectiveness because of fatigue. The objective of this study was to use simulation modeling to analyze how fatigue, crew size, and rotation schedule affect operator workload and performance during the control of a TUAV. Twelve different crew configurations, which ranged in size from 8 to 15 crew members, were examined for the TOC and the LRS.

5. Conclusions and Recommendations

The conclusions from executing the models and interviewing SMEs (during 12- and 18-hour missions) indicate that reducing the number of AVOs or MPOs in the TOC can result in more AV mishaps during emergencies, an increase in the time to search for targets, and a decrease in the number of targets detected. For example, compared to six AVOs or MPOs in the TOC, adding two crew members resulted in only slight performance gains of a 6% increase in target detection and a 4% decrease in target search time, whereas subtracting two crew members (four AVOs or MPOs in the TOC) resulted in substantial performance losses of a 20% decrease in target detection and a 15% increase in target search time. The general conclusion was that crews containing six AVOs or MPOs were the most efficient trade-off between performance and crew size.

Furthermore, analysis of the workload data produced by the model showed that when there was no MC in the LRS, the TOC MC was interrupted approximately 50% of the time with tasks that would have been performed by the LRS MC. When there was one MC in the LRS, the TOC MC was interrupted approximately 20% of the time with tasks that would have been performed by the LRS MC. According to SMEs, the following events can occur when the TOC MC is overloaded:

- Delay of an AV launch (i.e., the MC missed the launch time);
- The MC encounters problems coordinating the airspace;

- The MC is not supervising the AVO and/or the MPO;
- The MC fails to set the correct radio frequency, which can lead to the loss of an AV;
- The MC incorrectly performs the dynamic re-tasking, and targets are missed;
- Supervision of maintenance problems can be degraded;
- Fuel could be improperly loaded on the AV;
- Preventive maintenance checks and services may not be performed or documented properly;
- The MC could ignore poor-weather warnings, which could lead to the loss of an AV; and
- A jump may not be possible unless another soldier at the LRS can perform the MC’s duties.

Adding a third AVO to the LRS (compared to the baseline of two AVOs) was shown *not* to affect the performance of a mission. Therefore, of the crew configurations investigated, the crew size of 12 (TOC [two MCs and six AVOs or MPOs], LRS [two MCs and two AVOs]) proved to be the most effective during 12- and 18-hour missions. This recommendation must be verified during experimentation with actual performance and fatigue data to validate the model’s predictions. Also, we need to emphasize that the recommendations depend on the model’s assumption of a 12-hour shift and adequate rest during off-shift hours. Actual combat conditions, additional stress and duties, and operations longer than 72 hours may have further adverse effects on the crew’s ability to control the air vehicle and perform the target taskings.

Future work involves (a) revising the TUAV model after data from operational tests are received and (b) performing a maintainability assessment of the Shadow 200 TUAV. The revised model will be used to predict manpower requirements by simulating the maintenance requirements of a unit as the systems are sent on missions, sent to maintenance (as required), and then returned to a pool of available systems. Total crew composition will not be known until this study is completed. Total crew size includes this information plus data about administrative and supervisory personnel.

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APPENDIX A

TASK NETWORK OF THE MICRO SAINT SHADOW 200 TUAV MODEL

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TASK NETWORK OF THE MICRO SAINT SHADOW 200 TUAV MODEL

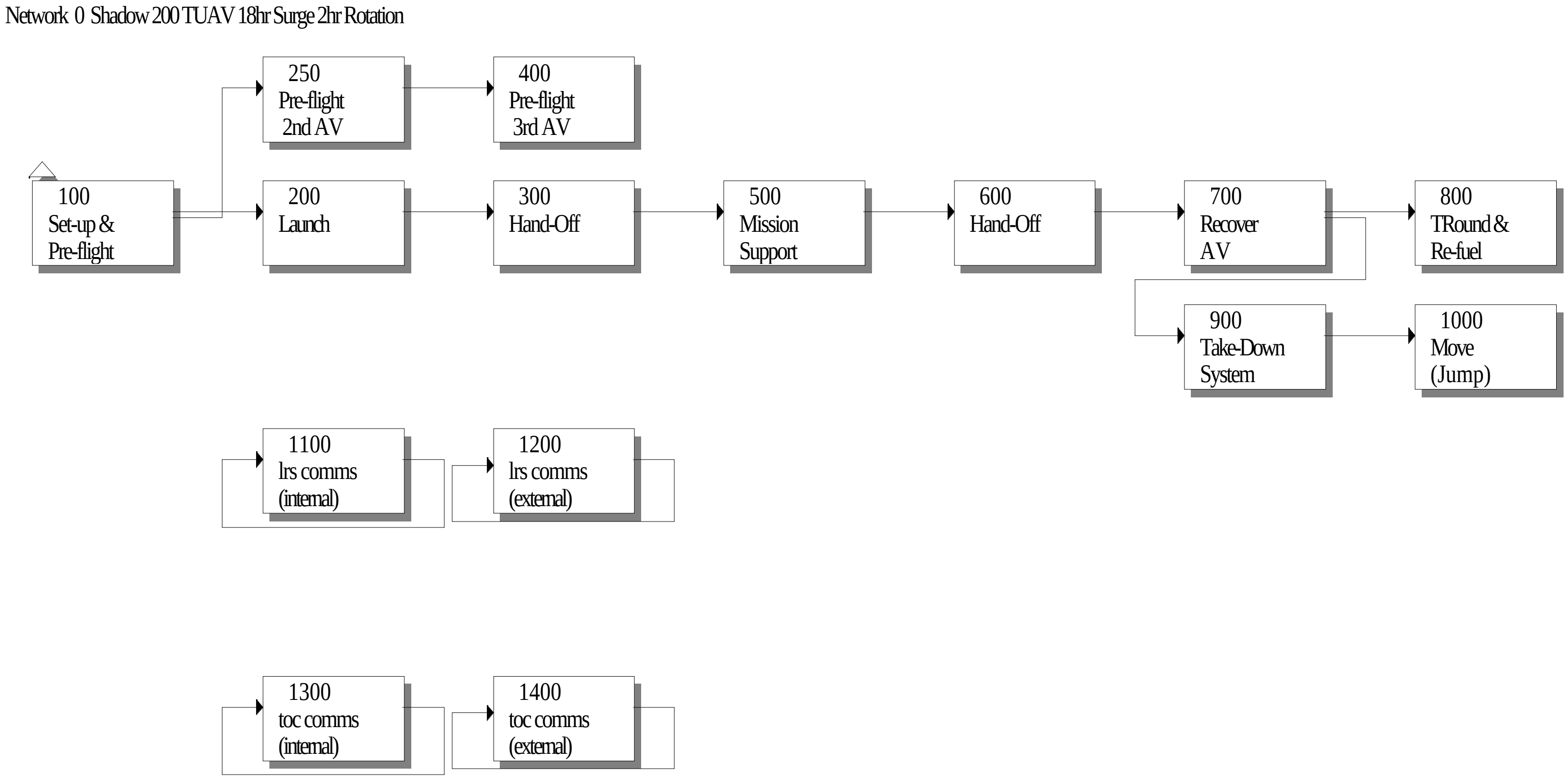

Figure A-1. Top Level of the Shadow 200 TUAV Model.

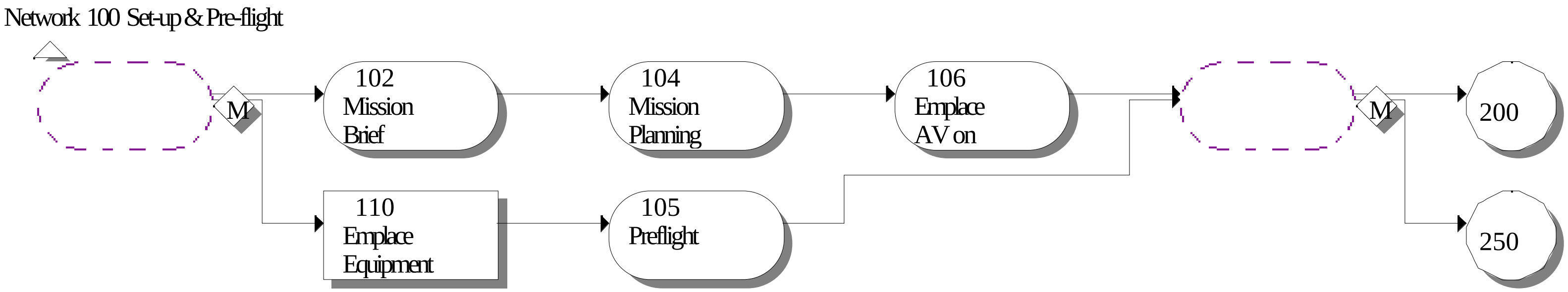

Figure A-2. Set-up and Pre-flight Sub-network.

APPENDIX B

ROTATION SCHEDULES

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ROTATION SCHEDULES

Table B-1. Rotation Schedules for the TOC (18-hour mission and one move every day)

TIME	UAV 1	UAV 2	UAV 3	2 MCs 8 AVO/MPOs 2-Hour Rotation	2 MCs 8 AVO/MPOs 3-Hour Rotation	2 MCs 6 AVO/MPOs	2 MCs 4 AVO/MPOs
0000	Planning & Setup			MC_1 & Op_A & Op_B	MC_1 & Op_A & Op_B	MC_1 & Op_A & Op_B	MC_1 & Op_A & Op_B
0030	Launch						
0100	AOO	Setup					
0130			Setup				
0200				Op_C & Op_D		Op_B & Op_C	
0230							
0300					Op_C & Op_D		
0330							
0400				Op_A & Op_B		Op_C & Op_A	
0430		Launch					
0500	Return	AOO					
0530	Land						
0600	Setup			Op_C & Op_D	Op_A & Op_B	Op_A & Op_B	
0630							
0700							
0730							
0800			Planning	Op_A & Op_B		Op_B & Op_C	
0830			Launch				
0900		Return	AOO		Op_C & Op_D		
0930		Land					
1000		Setup		Op_C & Op_D		Op_C & Op_A	
1030							
1100							
1130							
1200	Launch			MC_2 & Op_E & Op_F	MC_2 & Op_E & Op_F	MC_2 & Op_D & Op_E	MC_2 & Op_C & Op_D
1230	AOO		Return				
1300			Land				
1330							
1400				Op_G & Op_H		Op_E & Op_F	
1430							
1500					Op_G & Op_H		
1530		Planning					
1600		Launch		Op_E & Op_F		Op_F & Op_D	
1630	Return	AOO					
1700	Land						
1730							
1800				Op_G & Op_H	Op_E & Op_F	Op_D & Op_E	
1830							
1900		Return					
1930		Land					
2000				TD	TD	TD	TD
2030				Move	Move	Move	Move
2100							

Table B-2. Rotation Schedules for the LRS (18-hour mission and one move every other day)

TIME	UAV 1	UAV 2	UAV 3	0 MCs 2 AVOs	1 MC 2 AVOs	2 MCs 2 AVOs	2 MCs 3 AVOs
0000	Planning & Setup			AVO_1	AVO_1 & MC on	AVO_1 & MC_1	AVO_1 & MC1
0030	Launch						
0100	AOO	Setup					
0130			Setup				
0200							
0230							
0300							
0330							
0400							
0430		Launch					
0500	Return	AOO					
0530	Land						
0600	Setup						
0630					MC Off		
0700							AVO_2
0730							
0800			Planning				
0830			Launch				
0900		Return	AOO				
0930		Land					
1000		Setup					
1030							
1100							
1130							
1200	Launch			AVO_2	AVO_2	AVO_2 & MC_2	MC_2
1230	AOO		Return				
1300			Land				
1330							
1400							AVO_3
1430					MC On		
1500							
1530		Planning					
1600		Launch					
1630	Return	AOO					
1700	Land						
1730							
1800							
1830							
1900		Return					
1930		Land					
2000				TD	TD	TD	TD
2030				Move	Move	Move	Move
2100							

APPENDIX C

MISSION PROFILES FOR A 12-HOUR MISSION

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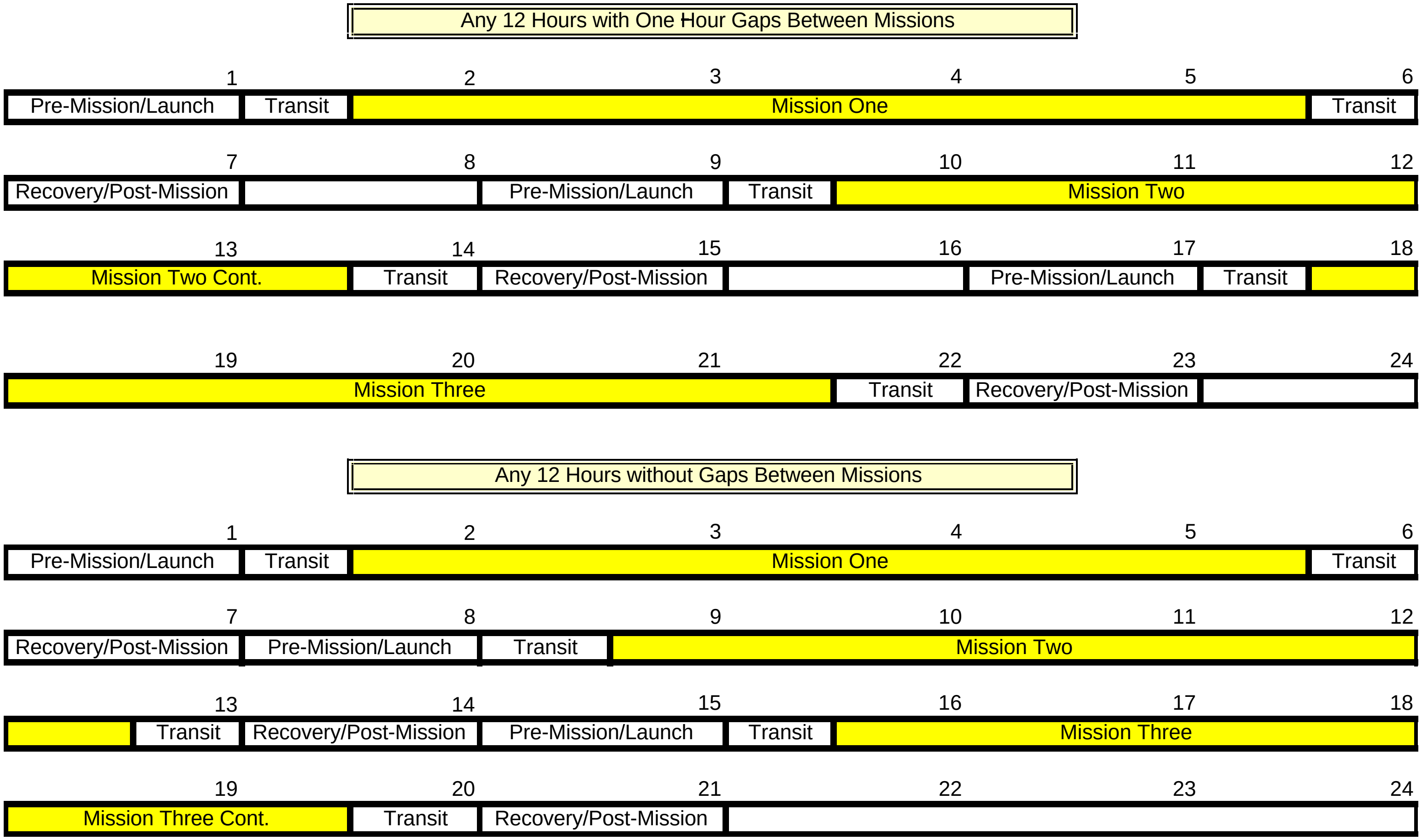
MISSION PROFILES FOR A 12-HOUR MISSION



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13. ABSTRACT *(Maximum 200 words)*

This report describes a study conducted by Micro Analysis and Design, Inc., for the U.S. Army Research Laboratory (ARL). One area of research examined by ARL was the staffing required to operate tactical unmanned aerial vehicles (TUAVs). The primary objective of the study was to use simulation modeling to analyze how fatigue, crew size, and rotation schedule affect operator workload and performance during the control of a TUAV. Computer simulation models were developed with the Micro Saint Discrete Event Simulation software to simulate the tasks that operators perform when controlling a TUAV. These models, which contain system-specific attributes of the Shadow 200 TUAV, included a fatigue function to predict performance effects for day and night missions. Subject matter experts (SMEs) provided the list of tasks involved in controlling a TUAV (during normal operations and emergencies), the order of these tasks, and the visual, auditory, cognitive, and psychomotor workload values associated with each task. Twelve different crew configurations were examined for the tactical operations center (TOC) and the launch and recovery station (LRS), which ranged in size from 8 to 15 crew members. The conclusions from executing the models and interviewing SMEs (during 12- and 18-hour missions) indicate that reducing the number of aerial vehicle operators (AVOs) and mission payload operators (MPOs) in the TOC can result in more aerial vehicle mishaps during emergencies, increased search time, and a decreased number of targets detected. For example, compared to six AVOs or MPOs in the TOC, the addition of two crew members resulted in only slight performance gains of a 6% increase in target detection and a 4% decrease in target search time. However, when the members of the crew were reduced to four AVOs or MPOs in the TOC, there was substantial performance loss (20% decrease in target detection and a 15% increase in target search time). The general conclusion is that a crew of 12 (TOC [two MCs and six AVOs or MPOs]; LRS [two MCs and two AVOs]) is the most efficient trade-off between performance and crew size. The implications of these findings for other possible crew configurations are discussed, along with plans for further analyses.

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