AFRL-RH-BR-TR-2009-0032

24/7 OPERATIONAL EFFECTIVENESS TOOLSET: SHIFTWORK SCHEDULER INTERFACE

James C. Miller
Douglas R. Eddy
Richard Smith
Samuel L. Moise

NTI, Incorporated
1 ½ South Central Ave
Fairborn, OH 45324

August 2008

Interim Report for Mar 2006 – Jun 2008

Air Force Research Laboratory
711 Human Performance Wing
Human Effectiveness Directorate
Biosciences and Protection Division
Biobehavioral Performance Branch
Brooks City-Base, TX 78235

NOTICE AND SIGNATURE PAGE

Using Government drawings, specifications, or other data included in this document for any purpose other than Government procurement does not in any way obligate the U.S. Government. The fact that the Government formulated or supplied the drawings, specifications, or other data does not license the holder or any other person or corporation; or convey any rights or permission to manufacture, use, or sell any patented invention that may relate to them.

This report was cleared for public release by the 311th Public Affairs Office at Brooks City Base, TX and is available to the general public, including foreign nationals. Qualified requestors may obtain copies of this report from the Defense Technical Information Center (DTIC) (http://www.dtic.mil).

AFRL-RH-BR-TR-2009-0032 HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION IN ACCORDANCE WITH ASSIGNED DISTRIBUTION STATEMENT.

_____//SIGNED//_____	_____//SIGNED//_____
SHARON K. GARCIA	MARK M. HOFFMAN
Work Unit Monitor	Deputy Division Chief
Biobehavioral Performance Branch	Biosciences and Protection Division
	Human Effectiveness Directorate
	711 Human Performance Wing
	Air Force Research Laboratory

Approved for public release; distribution unlimited. Public Affairs Case file no. 09-295, 29 June 2009.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
26-08-2008	Interim Technical Report	3-30-2006 to 6-30-2008

4. TITLE AND SUBTITLE
24/7 Operational Effectiveness Toolset: Shiftwork Scheduler Interface

5a. CONTRACT NUMBER
FA8650-06-C-6606

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
James C. Miller, Douglas R. Eddy, Richard Smith, and Samuel L. Moise

5d. PROJECT NUMBER
5020

5e. TASK NUMBER
P9

5f. WORK UNIT NUMBER
09

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

NTI, Inc.
1 ½ South Central Ave.
Fairborn, OH 45324

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Air Force Materiel Command
Air Force Research Laboratory
711 Human Performance Wing
Biosciences and Protection Division
2485 Gillingham Dr.
Brooks City-Base, TX 78235

10. SPONSOR/MONITOR'S ACRONYM(S)
711 HPW/RHPF

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFRL-RH-BR-TR-2009-0032

12. DISTRIBUTION / AVAILABILITY STATEMENT
Distribution A. Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This report describes the Shiftwork Scheduler Interface of the 24/7 Operational Toolset. The toolset was based upon the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE™; Hursh et al., 2004) model. The SAFTE™ model predicts cognitive performance level based upon sleep, circadian rhythm, and sleep inertia. This specific interface of the toolset was designed to aid in the construction of regular, rotating, 24/7 shiftwork schedules. The interface design approach was iterative, involving several meetings among subject matter experts (SMEs), interface software designers, and evaluators. The first meeting was for the purpose of requirements analysis, in which the designers elicited task information from the SMEs. The second meeting included a walk-through of storyboarded and preliminary software, in which the SMEs provided feedback to the designers and evaluators. The final meeting was for the purpose of an "inspection evaluation" of the interface by the SMEs and evaluators. This interface was based upon task analyses of AF Security Forces shiftwork schedulers and they served as our SMEs. Our requirements analysis indicated that the shiftwork scheduler's interface should meet several criteria to maximize usability. Walk-through and inspection evaluation processes indicated that most of these requirements were met reasonably well and that potential users were able to operate the interface with a minimum of errors.

15. SUBJECT TERMS
Shift work, Fatigue management, Cognitive performance, Task analysis, Sleep times

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(include area code)*
U	U	U	SAR	39	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

This page left intentionally blank

PREFACE

The contract technical monitors for this work were Drs. James C. Miller and Scott Chaiken, and the program managers were Lts Andrea M. Pinchak and Andrew J. Workman, Biosciences and Protection Division, Air Force Research Laboratory.

Special thanks to Lt Col Krista Wenzel and Capt Robert L. Moore of Headquarters, Air Force Security Forces Center, Lackland AFB, TX for their support of this effort. Additional thanks go to Beth Barker for handling financial relationships with the government and our subcontractors.

TABLE OF CONTENTS

TABLES

SUMMARY

This report describes the Shiftwork Scheduler Interface of the 24/7 Operational Toolset. The toolset was based upon the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE™; Hursh et al., 2004). The SAFTE™ model predicts cognitive performance level based upon sleep, circadian rhythm, and sleep inertia. This specific interface of the toolset was designed to aid in the construction of regular, rotating, 24/7 shiftwork schedules. The interface design approach was iterative, involving several meetings among subject matter experts (SMEs), interface software designers and evaluators. The first meeting was for the purpose of requirements analysis, in which the designers elicited task information from the SMEs. The second meeting included a walk-through of storyboarded and preliminary software, in which the SMEs provided feedback to the designers and evaluators. The final meeting was for the purpose of an "inspection evaluation" of the interface by the SMEs and evaluators. This interface was based upon task analyses of AF Security Forces shiftwork schedulers who also served as our SMEs.

Our iterative sessions with SMEs indicated that the shiftwork scheduler's interface should (a) provide a mechanism that allows schedulers to make informed decisions with respect to all of the principles and components of shiftwork scheduling, and to make "what-if" comparisons across various alternative schedules; (b) make comparisons in terms of a specific schedule's compliance with the shiftwork scheduling principles and in terms of points within a schedule that are particularly fatiguing, identified by the SAFTE model; (c) suggest countermeasures to be used when mishap risk is higher than normal; (d) constrain the potentially infinite possibilities for shiftwork schedules to those that make the most sense in terms of nine shiftwork principles; (e) be both minimal in scope and provide extensive optional guidance with respect to the nine principles and nine components of shiftwork scheduling; (f) make the shiftwork scheduling manual available for study and review; (g) identify clearly the "fatigue points" in the proposed schedule; (h) allow side-by-side comparisons of several candidate schedules. The walk-through and inspection evaluation processes indicated that most of these requirements were met reasonably well and that potential users were able to operate the interface reasonably easily.

24/7 Operational Effectiveness Toolset:
Shiftwork Scheduler Interface

INTRODUCTION

This project was aimed at designing several interfaces for a browser-based tool that could help in the construction of work-rest schedules: the Fatigue-Performance Assessment System (F-PAS). The tool was based upon the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE™; Hursh et al., 2004) model. The SAFTE™ model predicted cognitive performance level based upon sleep, circadian rhythm, and sleep inertia. Previously, the SAFTE™ model had been implemented in the Windows software named the Fatigue Avoidance Scheduling Tool™ (FAST™; Eddy & Hursh, 2001, 2006). This report describes the development of the F-PAS interface for regular work-rest schedules normally associated with shiftwork and is called the Shiftwork Scheduler Interface (SSI). The tool contained a set of rules that determine the likely sleep times of an individual for starting work at specific, irregular times (Foret & Lantin, 1972; Pollard, 1996; Reid *et al*., 1997). Once the sleep times were determined, the model predicted cognitive performance effectiveness for the work interval or work shift.

The overall design approach used in this project was iterative, involving several meetings among subject matter experts (SMEs), interface software designers and evaluators. The first meeting was for the purpose of requirements analysis, in which the designers elicited task information from the SMEs. The second meeting included a walk-through of storyboarded and preliminary software, in which the SMEs provided feedback to the designers and evaluators. The final meeting was for the purpose of an "inspection evaluation" of the interface by the SMEs and evaluators. This interface was based upon task analyses of AF Security Forces shiftwork schedulers.

Prior to conducting the requirements assessment session described here, we were aware of two especially relevant USAF reports. The first described the Eagle Look concerning shiftwork-induced fatigue (AF Inspection Agency, 2004). In short, this all-USAF review concluded that the AF had no method for detecting or tracking shiftwork-fatigue related mishaps, inadequate training concerning shiftwork-induced fatigue, and little or no policy or guidance concerning shiftwork scheduling.

The second report provided a principle-based approach to shiftwork scheduling (Miller, 2006). The report discussed shiftwork-induced fatigue, safety, calendar arithmetic, circadian stability, the Principles of Chronohygiene, shiftworker satisfaction, the number of shiftworkers needed, the basic structure of shiftwork systems, and plans (rotas), scheduling methods and examples, and the effects of schedule changes. It cited the use by USAF Security Forces of one specific, slow rotation plan. That plan, or rota, was called the "Panama" or "every-other-weekend-off" rotation. It is described under Requirements Analysis, Security Forces Practices in the Discussion section.

METHODS

A more detailed explanation of the methods used here may be viewed in the companion technical report, *24/7 Operational Effectiveness Toolset: Usability Assurance Plan* (Miller, Eddy & Moise, 2008). The SME sessions were conducted by NTI under the auspices of the AF Security Forces Center, Lackland AFB, Texas, and were held in their offices and laboratory at Lackland AFB.

REQUIREMENTS ANALYSIS

The first session was held at the Security Forces (SF) headquarters building at Lackland AFB on 24 and 25 July 2006. Three SF SMEs participated: two Senior Master Sergeants and a Master Sergeant.

The agenda for the first session was as follows:

- Introductions, goals and objectives (NTI)
- Fatigue Management overview (NTI)
- Participant overview of their tasks and background (SMEs)
- Introduction to task analysis (TA) and procedures (NTI)
- TA: goals and processes
- TA: tasks
- Review of goals and tasks
- Usability assessment of FAST™

To initiate discussions, NTI described fatigue terminology and fatigue management concepts to provide a common understanding of fatigue and performance. The researchers used FAST™ graphs to briefly discuss and demonstrate the impact of fatigue on cognitive performance.

WALK-THROUGH

From the user task descriptions and the requirement assessment (RA), we created scenarios for user testing and review. In the walks through the draft interface, the designers, potential end users, and evaluators worked together to step through typical tasks for which the interface was designed. The users were given preliminary training in fatigue management, on the capabilities of the browser-based tool called Fatigue-Performance Assessment System (F-PAS) and on the draft SSI. The designers demonstrated the tool by entering data for a fictitious scenario. Questions and discussions accompanied each screen of the tool.

We roughly estimated the total number of usability problems in the interface from the number of problems (E) identified during the walk-through. Assuming a detection rate of about 30% in the walk-through, the total number of problems would be about equal to E divided by 0.30 (Bailey, 1997).

INSPECTION EVALUATION

In the inspection evaluation, representative end users tried to do typical tasks with the interface while a designer/evaluator watched, listened, and took notes. We wished to identify usability

problems, collect quantitative data on participants' performance and determine the participants' satisfaction with the product. More specifically, we wished to learn:

- Could the test participants complete the relevant tasks successfully?
- How long did it take the participants to do each subtask?
- Did the participants perform well enough to meet their usability objectives?
- How satisfied were the participants with the interface?
- What changes were needed to make sure that the interface would enable more users to perform more successfully?

These latter questions were addressed through the questionnaire shown in Appendix A. The observer collected detailed data using the scoring sheet shown in Appendix B. The user was provided with a separate document showing the 34 questions in the scoring sheet.

RESULTS

REQUIREMENTS ANALYSIS

The SMEs provided a brief overview of their role in shift work scheduling, and outlined who might be the primary users of our new fatigue management tool. They indicated that their security forces had three security missions:

- Nuclear assets, the highest priority
- Garrison, working at well-established USAF sites
- Deployed forces, working in combat areas

Potential Users

Regarding potential users, the SMEs indicated that the Security Operations Officer (O-3 to O-4) and the Operations Superintendent (E7 to E-8) would be primary and the software interface would need to meet their needs. Additionally, they indicated that the interface design should also consider the needs of the Flight Sergeant and Commander since they would likely use the tool as well. They indicated that it would not be necessary to consider the needs of security personnel at the grade of E-4 and below in the design process.

In discussing the skill and abilities of our users, the SMEs felt that users would be E-5s or higher. They would be high school graduates with some college work, familiar with the internet, and familiar with browser-based tools. An E-6 would have had 5-10 years of security experience before becoming an Operations Superintendent. Security personnel receive training at AF Regional Training Centers and at each major command.

The Operations Officer and Operations Superintendent set the general orientation for post assignments after a site is considered secure. They also set the shift start times. The Flight Sergeant decides who works when and where. The SMEs indicated that schedules were created out of the post requirements and work force available. Other inputs were secondary. Generally, schedules were created without considering whether off-duty days occurred on weekends.

Task Analysis

Next, the task analysis (TA) procedures were introduced and the process was begun. We asked the SMEs to list their goals and processes along with the tasks that accomplished them. Each of eight goals and processes was discussed thoroughly. An overview of the task analysis results is shown in Table I. Discussion with the SMEs focused on how schedules were created; thus, the automation potential for tasks was not considered in much depth during these discussions.

TABLE I. Overview of the task analysis results

	PROCESSES/GOALS STEPS	TASKS TO ACCOMPLISH	SUGGESTED AUTOMATION
1.	Site survey	A. Terrain analysis: Determine security boundary, threats, TAOR* B. Determine duration C. Determine weapons available for defense D. Determine security requirements to calculate required manpower	
2.	Prioritize post assignments	E. Determine work demand per security post F. Develop post priority chart	
3.	Determine personnel needed	G. Determine skill levels required per position H. Consider manning ratio (post manning factor) I. Determine rotation schedule (Consider rota or plan) J. Determine whether to use 8- or 12-hour shift length K. Determine shift change time	Provide scheduling options and schedule comparisons
4.	Determine number of elements	L. Consider work/rest schedule (days off) & mandated components	Provide scheduling options and schedule comparisons
5.	Leadership validation of proposal	M. Incremental changes	Provide schedule editing functions
6.	Implementation	N. Dissemination of duty schedules O. Consider day of week for start	
7.	Schedule feedback (expected evolution)	P. Observe performance and adjust based on experience	Provide schedule editing functions
8.	Maintenance	Q. Attend to changing schedule requirements	Analyze impact of change on replacement person

Notes: This Table starts with the firsts steps in shift work scheduling and progresses through to approval, schedule feedback and schedule maintenance. Data in each column move from left to right, from global Process/Goals, to specific Tasks that are directly related to those stated processes/goals. The last column addresses how an automated tool, such as FAST™ might facilitate the tasks.

*TAOR: tactical area of responsibility; the area that the defense force commander can control through organic heavy/light weapons fire.

Generally, the scheduling process emulated the following logic:

1. Survey the site to be protected, determining the work demand and the human and weapons resources needed
2. Prioritize all of the security posts that would be manned

3. Calculate the specific numbers and kinds of SF personnel needed to do the job and their shift schedule(s)
4. Determine how to break the needed personnel into flights and elements (shiftwork crews)
5. Secure minor revisions and approval from senior leadership
6. Implement the final plan
7. Monitor the adequacy of the schedule
8. Make changes to the schedule, as needed

Concerning the eighth step, *ad hoc* modifications to shiftwork schedules occurred in response to varying security demands. The modifications were implemented by increasing the ratio of work days to days off and by ceasing to guard low priority posts temporarily in favor of higher-priority, transient demands for security. Generally, transiently-increased security demands could not be met by increased numbers of Security Forces personnel due to their scarcity.

On the second day of the session, we began by reviewing the eight goals and processes and their associated tasks to make corrections. Table I reflects the few changes made during the review. Next, the SMEs provided additional information related to each of the tasks: what or who started or initiated each task or group of tasks, what media was used to complete the task, the input information required of the task, and what the output product was. This information is captured in Table II.

With respect to shiftwork scheduling, Tasks A through G in Table II deal with personnel selection issues that precede actual scheduling. Tasks H through J deal with an essential question: Are there enough people (of the needed skill levels) to support 24/7 operations? Tasks K through O address actual shiftwork scheduling. Tasks P through V deal with the implementation and maintenance of the schedule.

TABLE II. Task characteristics within each goal

TASKS WITHIN GOALS/PROCESSES	DIRECTIVES	MATERIALS AND MEDIA	INPUTS	OUTPUTS
1. Site survey tasks	Air Tasking Order, Air Staff, Major Command	Electronic		Tasking order includes images & text; the "Big Picture"
A. Terrain analysis: establish security boundary, define threats, TAOR				
B. Determine duration				
C. Determine weapons needed				
D. Determine manpower requirement				
2. Prioritize post assignments (tasks)	Senior Security Forces leadership		Own unit analysis of site	

TASKS WITHIN GOALS/PROCESSES	DIRECTIVES	MATERIALS AND MEDIA	INPUTS	OUTPUTS
E. Determine work demand per post	AFI 31-101, DOD C-5210 .41-M	Electronic/paper		No. of people & skills
F. Develop post priority chart		Electronic/paper		Post Priority Chart
3. Determine personnel needed for posts		Final electronic	Unit Manning Document	Allocation of flights
G. Determine skill levels required by position	Operations officer	Paper/pencil, white board	Leader's planning	Duty roster template
H. Consider manning ratio				
I. Establish rotation schedule				
J. Choose 8- or 12-hour shift length			12-hour is default	
K. Consider change time			Traffic, desert temps., meals	Time; usually same for all elements
4. Determine number of elements		Final electronic	# of personnel & post manning requirements; day to day	on:off duty ratio = 3:1, 4:1, 5:1
L. Consider work/rest schedule (days off) mandated components		Paper/pencil, whiteboard		
5. Leadership validation of proposal tasks (at squadron level)		Final electronic	Verbal/textual input (duty rosters)	Yes/change
M. Incremental changes		Paper/pencil/ whiteboard		
6. Implementation tasks			Duty roster template	Duty roster
N. Dissemination of duty schedules		Paper, electronic		
O. Consider day of week for start	Ops Officer			
7P. Schedule feedback (expected evolution) tasks	Input from those scheduled	Paper/pencil, whiteboard, final electronic	Duty roster	Revised duty roster
8Q. Maintenance tasks	Events requiring schedule change	Paper/pencil, whiteboard, final electronic	Duty roster	Temporary duty roster

Other information offered during the sessions included the following:

- USAF Security Forces were suffering from a large work force shortage.
- Work/rest schedules usually lasted about 30 days. Generally, the Security Forces embrace this slow rotation philosophy.

- Morale was a big issue for the security forces leading to retention resistance. They attributed low morale to regularly losing one day of leave each month due to extra duties.
- They conducted training on "off" days usually one day per month. (The concept of a 5th element was discussed for accomplishing training.)
- The number of people and the number of posts determined the duty roster template.
- The ratio of on- versus off-duty personnel was generally 3:1.
- Raven forces sometimes used No-go drugs (approved sleeping pills), under medical supervision, for rest during difficult missions or poor sleeping conditions. "Air Mobility Command's Phoenix Raven program, implemented in 1997, consists of teams of specially trained security forces personnel dedicated to providing security for AMC aircraft that transit high terrorist and criminal threat areas." (usmilitary.about.com)
- Security Forces personnel venerated the Raven program for their fast deployments. Raven teams deployed approximately once every two to three months.

Documents referenced during the Task Analysis included:

- DoD C-5210.41-M, Nuclear Weapon Security Manual (U)
- AF 31-101, The Air Force Installation Security Program, provides information on required staffing for various posts (security sites). The Air Combat Command supplement contains additional useful information on alternate posts.
- AF 31-302, Air Defense Handbook, provides guidance for the collective skills required to carry out the Air Force air base defense mission.
- AF 31-305, Security Forces Deployment Planning Handbook, provides Security Forces Commanders and planners with the basic requirements for deployment planning and execution in support of operational and contingency plans, Aerospace Expeditionary Force, and contingency deployment and redeployment operations. It provides basic information on Unit Type Code development, use and capabilities.

Usability of FAST™

The SME's reactions to version 1.5 of FAST™ were typical for non-scientists. They found the graphical input/output interface to be confusing and the grid input interface to be potentially useful. They desired the ability to make "what-if" comparisons across various schedules in the output component of the interface.

INTERFACE PLANNING

Previously, we had considered several aspects of shiftwork scheduler output interfaces and their advantages and disadvantages for application in a 24/7 Scheduler (Eddy and Hursh, 2006). These ideas for a 24/7 output interface were the result of the shortcomings of the FAST™ output display that showed a schedule for only one person or one crew. Shift work schedulers need to see the impact of their schedule on all shifts or crews to compare the benefits and costs of different schedules. The conceptual displays presented by Eddy and Hursh were intended to allow schedule comparisons across all crews. Unfortunately, we were unable to identify an

algorithm that would calculate crew lag reliably for all possible shiftwork schedules. Thus, the lag calculation task was not automated. Instead, the interface was designed to advise the user:

> The solution created from your inputs here refers only to one crew in a 4-crew plan. To integrate all 4 crews into a single schedule, find the lag time manually from crew start to crew start. To do this, lay out four copies of the whole single-crew cycle and slide them against each other until, scanning across the 4 crews, you see that each shift is covered once per day, and no more than once per day. Here is an example. Note that for 4-crew solutions, one-quarter of the days in a cycle must be off (O) days for 8-hour shifts, and one-half of the days in a cycle must be O days for 12-h shifts.

The example provided was:

> Because the solutions offered here deal only with a single crew, you need to find the number of lag days before the next crew starts the same schedule. Unfortunately, there is no magic formula (yet) for calculating the number of lag days. The number of lag days is usually the value of F (free days) from your shift system, or one-half of F. It may also be all or half the total of W and F.
>
> Draw a table with one column for each crew and a line for each day in the cycle. Write in the Crew A schedule in column 1, from top to bottom. Count down the expected number of lag days from the start of Crew A's plan, and, starting at that point, pencil in the same plan for Crew B in the Crew B column, to the right of the Crew A column. Pencil in the same plan for Crews C, D, etc., using the same number of lag days from the crew to the left, and using the same plan. From the bottom of each column, wrap around to the top of that column and continue penciling in the schedule.
>
> Then, scan across each day. If you are using 12-h shifts, look for one and only one D in each day's line, one and only one N in each day's line. If the column meets these criteria, place a check mark for that day in a summary column at the right for that day. If you are using 8-h shifts, look for one and only one D, one and only one S, and one and only one N in each line. If the column meets these criteria, place a check mark for that day in the summary column at the right for that day.
>
> If all days meet the criterion, then one crew fills each shift on every day of the cycle. This is what you want. If some lines do not meet this criterion (some check marks are missing), then go back and try another number of lag days. Make sure that you are using the same plan in every crew column. If, after trying all lag lengths from one up to the total of the W and F in your system, you cannot fill each shift with one crew each day, you need to re-examine your decisions about numbers of crews and numbers of shifts per day.
>
> A non-table way to find the number of lag days is to type out the plan several times, print it out, cut it into strips, and move the strips back and forth next to each other until you have only one crew per shift per day. Your typing might look like this for four cycles of the 4-crew, 12-h, DDNNROOO plan:

Crew A: D D N N R O O O D D N N R O O O D D N N R O O O D D N N R O O O
Crew B: D D N N R O O O D D N N R O O O D D N N R O O O D D N N R O O O
Crew C: D D N N R O O O D D N N R O O O D D N N R O O O D D N N R O O O
Crew D: D D N N R O O O D D N N R O O O D D N N R O O O D D N N R O O O

Though we were unable to implement one of the multi-crew-displays suggested by Eddy and Hursh (2006), the discussion illustrated to us the need for innovation in how we would present SAFTE output data to the shiftwork scheduler.

WALK-THROUGH

Three walks through the draft software were conducted at Lackland AFB with SMEs provided by the SF Center.

First Walk-Through

Dr. Miller walked several SMEs through the first draft of the interface on 11 September 2007. The draft was designed to place a constrained amount of information about shiftwork scheduling on a single web page. The material was drawn from Miller (2006). The main thrusts included hyperlinked pop-up windows that presented somewhat-detailed information about scheduling, a constrained set of known shiftwork plans and a method for acquiring a simple analysis of a new plan.

The draft was generally well received. Twenty one questions and recommendations resulted from the walk-through, suggesting that there might have been as many as 70 possible improvements that could have been identified (21/.3 = 70; Bailey, 1997).

- Explain shift overlap clearly.
- What is the reference for a relative risk of 1.0 on the shift length graph?
- The color red may indicate to some commanders that the fatigue risk is too great to accept. On the other hand, some commanders may note that they have been operating extensively in the "red" without mishaps and so may ignore it. Possible solution is to use a different color for the known, pre-dawn trough.
- Support the problem of under-manning better.
- Emphasize BAC equivalency.
- Use a translation [truth] table for effectiveness, BAC and relative risk. Also, put truth tables in examples of shiftwork schedules.
- Add a fatigue countermeasures (risk mitigations) list.
- Recommend not covering lower-priority posts to reduce fatigue risk.
- Use many fewer words. Look at Army websites for ideas on game-like graphics. Never require the user to scroll the page.
- Suggest the home page contain the three satisfaction principles, then three buttons for selecting introductory material, worked examples, or schedule creation.
- When displaying various shift choices highlight the four-crew solution and emphasize satisfaction principles.
- Add a pop-up for driver fatigue case law related to off-base risk.
- Use an easily accessible effectiveness graph, with tool tips.

- Use a threshold warning: i.e., use the dotted line display concept used in FAST.
- "Stand-to" time occurs pre-dawn, when it is known that attentiveness is poor and threat is high. How might we use this info?
- Enter data using a calendar, as in Outlook. Show shift overlap in shades of gray.
- The crew number graph is good. Increase its importance.
- Consider Palm Pilot (PDA) use at some point.
- The site needs a guide to analyzing a present shiftwork schedule.
- Use shading in shift plan tables to show each shift. For example:

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Day							
Swing							
Night						12	12

Note: All shifts are 8 hours long unless noted

In response to these questions and recommendations, the following changes were made to the interface:

- The page was split into five smaller pages: Home, New SF Plan [Security Forces], Known Plans, New Plan, and Additional Information. The Home page emphasized having enough people, using four crews and paying attention to worker satisfaction.
- A pop-up was added that explained shift overlap, and it was linked from both the Home and Additional Information pages.
- The color blue was used for the known, pre-dawn trough, instead of red on the output page.
- The problem of under-manning was emphasized more by adding both a pop-up and a calculator. These were linked from both the Home and Additional Information pages.
- A fatigue countermeasures (risk mitigations) list was added in a pop-up and it was linked from the Additional Information page and the output page. It recommended not covering lower-priority tasks to reduce fatigue risk at the remaining posts.
- The output page was changed to use color-coded shading in a shift plan table to show each shift.

Second Walk-Through

Dr. Miller walked several SMEs through the revised pages on 24 September 2007. The new design was also well received. The 14 new recommendations of the SMEs were to:

On the Home page:

- Create links to the shiftwork manual and the shiftwork survey report.
- Add a note about task-specific fatigue and the 20-minute vigilance decrement.

On the New SF Plan page:

- Use the employment ratio calculator instead of a ratio assumption.
- Add a work force disclaimer re AFPC manning policy.
- Add a line for number of deployment days on the ratio calculator page.
- Countermeasures pop-up:
  - Add more information on the best times to nap.

    - Add more information about caffeine use.
    - Add a disclaimer about the Personnel Reliability Program for the modafinil paragraph.

- Analysis page
    - Add a disclaimer about the average sleeper vs. long and short sleepers.
    - Add a disclaimer about the assumption that appropriate amounts of sleep are acquired during time off.
    - Orient the week's table in the output more horizontally and add space between rows.
    - Add a link to the countermeasures pop-up after the definition of "yellow."
- Add FAST graphs in all known-plan pop-ups.
- Build a stand-alone version of the interface (no connection to SAFTE engine on server).
- In the SAFTE engine, add a shift overlap period that is additive with the commute period.

In response to these questions and recommendations, the following changes were made to the interface:

On the Home page:
- Added links to the fatigue countermeasures and SAFTE pop-ups.
- Added links to the shiftwork manual and the shiftwork survey report.

On the New SF Plan page:
- Used the employment ratio calculator instead of a ratio assumption.
- Added a work force disclaimer re AFPC manning policy.

On the Analysis page:
- Added sentences about the average sleeper vs. long and short sleepers.
- Added a sentence about the assumption that appropriate amounts of sleep are acquired during time off.
- Oriented the week's table in the output more horizontally and added space between rows.
- Added a link to the countermeasures pop-up after the definition of "yellow."

On the countermeasures pop-up page:
- Added sentences about sleep aids, with a Personnel Reliability Program (PRP) disclaimer.
- Added a disclaimer about the PRP for the modafinil paragraph.
- Added a few more words about caffeine use.
- Added sentences on the best times to nap.
- Added a sentence about the pre-dawn "stand-to" time in the Double Checking paragraph.

Other
- On the ratio calculator page, added a line for number of deployment days.
- On the shift length pop-up page, added a note identifying the reference for a relative risk of 1.0. Added similar notes for other relative risk graphs in other pop-ups.
- On the SAFTE pop-up page, added paragraphs about task-specific fatigue and the vigilance decrement.

- Created a translation (truth) table for effectiveness, BAC and relative risk; linked from Additional Information page. Included technical references for data sources.
- Added a paragraph concerning shiftworker driver fatigue on the Additional Info page, with links to local NHTSA materials.

The following tasks were postponed:

- Build a stand-alone version of the interface (no connection to SAFTE engine on server). This version would lack the "New Plan" page and would be hosted on a SF server.
- Use an easily accessible effectiveness graph, with tool tips.
- Enter data using a calendar, as in Outlook. Show shift overlap in shades of gray.
- In the SAFTE engine, add a shift overlap period that is additive with the commute period.
- Add a brief help file, context sensitive, explaining the rationale for each page.
- Change ratio calculator lines from fixed words to defaulted text boxes.
- Protect from employment ratio < 1 errors.

Final Walk-Through

Dr. Miller walked several SMEs through the revised pages on 19 February 2008. The objective of the meeting was to update the SF Center personnel on the new web site, show them the Shiftwork Scheduler Interface on line for the first time, review changes made in response to the second walk through, and plan for usability testing. These objectives were met.

The site and the interface pages were accessible from one of the SF computers in the building. For usability testing, The SFC agreed to recruit up to 6 "operations types" who were experienced in unit-level (squadron) schedule planning. Three new, interesting issues came up in discussions. First, the SMEs noted that the interface will be good for unit-level, "macro" scheduling. Then, schedulers at the flight and element levels may use the Mission Scheduler interface to decide how to schedule personnel within 12-h shifts.

Second, when asked about alternative schedules for use in usability testing, the SMEs mentioned that a two-flight, three-element plan with 5 days on and 2 days off and 12-h shifts was used quite a bit. This may really be a 6-crew solution and SF may be able to use fewer people with a 5-crew system. This possibility should be described in the Help file. Finally, the SMEs noted that schedulers simply do not grasp the concept that changing from 8-h shifts to 12-h shifts does not decrease the number of people needed. This point must be emphasized in the Help file.

INSPECTION EVALUATION

Six senior non-commissioned officers participated as representative users: one retired Senior Master Sergeant (SMSgt; E-8), four SMSgts on active duty, and one Master Sergeant (E-7) on active duty. All were assigned to the SFC, with the retired SMSgt working there as a contractor. They were tested individually on the mornings of 25, 28 and 29 September 2008 at the Modeling and Simulation Branch of the SFC. A Lackland AFB desktop computer with Internet access (Windows XP) was used for all testing. There were no login or display format problems.

The participants' mean total active duty time was 22.8 years (range, 19 to 25 years). Their mean "years spent in shiftwork and/or night work as worker and/or scheduler" was 15.0 years (range, 6 to 20 years). Only one of the six participants, the retired SMSgt, had used FAST previously, and that was for staff work at the SFC.

Interface Ratings

The ratings (Appendix A) provided by the participants concerning the interface were:

Dimension	Median	Mode	Range
Ease of application	2	2	1 to 3
Performance	1	1	1 to 4*
Overall function	1.5	1	1 to 3

*The single rating of 4 reflected the single instance of server accessibility failure described below

Where the ratings were defined as:

1. Very acceptable
2. Acceptable
3. Borderline
4. Unacceptable
5. Very unacceptable

Since there was no help system operating at the time of testing, the "support" dimension was not rated.

Times

The mean times spent on each page and per question were:

Page	Mean (min)	per Q (min)
Home	3.33	1.11
New SF Plan	3.67	1.83
Known Plans	6.00	1.50
New Plan*	10.75	2.15
Additional Info	20.75	1.04
Sum	44.5	

*n = 4

Numbers of Assists and Errors

The raw numbers of assists and errors, and assists and errors per question (corrected for missing data) were:

Page	# Assists	# Errors	Assists per Q	Errors per Q
Home	5	3	1.57	0.94
New SF Plan	7	3	3.5	1.5
Known Plans	9	1	2.25	0.25
New Plan*	9	3	1.21	0.4
Additional Info	11	3	0.55	0.15

*n = 4

There were no reversals (backing up within or across pages) because of errors, and all tasks were completed with one major exception (below). Eight errors were rated as being a "minor problem." These are described, below. No error was rated as being a "show stopper."

The one major task completion failure occurred during the test period of the 5th participant. At approximately 08:45 CDT, while the participant was using the Known Plans page, the F-PAS server accessibility slowed dramatically, with pop-up windows requiring several minutes to appear. Accessibility was equally slow on the back-up testing system, which used a cellular modem to connect to the Internet. Since two different Internet access methods were impeded, it was assumed that an Internet failure had occurred somewhere in the line of communication between San Antonio and the physical location of the F-PAS server, or that there had been a failure at the server, itself.

The 5th participant used an alternate F-PAS web site to test the Additional Information page. The server accessibility problem continued through at least 11:00 CDT, including the testing period of the 6th participant. Thus, that participant also used the alternate web site to test all pages. Unfortunately, the alternate web site had no access to the core software, thus these two participants were not able to test the New Plan page. This resulted in the reduced sample size (n = 4) shown above for the mean time, assist and error data.

Our subsequent investigations revealed that host server had failed and that the Web host was somewhat unreliable. Consequently, for this and other reasons concerning graphics-package compatibility, a change was made subsequently to a new Web host.

Error Descriptions

The eight errors rated as being a "minor problem" are described here. First, one of the participants was unable to detect the information on the Home page indicating that the software could not prevent the effect of fatigue on mental performance.

Second and third, two of the participants were unable to identify two of the four "secrets" to shiftwork scheduling that were listed on the Home page. Fourth, the presence of the calculation form on the New SF Plan page interfered with a participant's ability to locate the Employment Ratio calculator, which was hyperlinked from that page.

Fifth, one participant was unable to determine where to start using the calculator on the New SF Plan page, and (sixth) was unable to find the number of available, qualified people who would not be included in the shift schedule.

Seventh, on the Analysis output generated from the New Plan page, the text above the table did not allow the participant to identify clearly the need for the application of fatigue countermeasures for the red-coded shifts. Eighth, on the Additional Information page, one participant was unable to determine from the text that a shiftwork schedule is more than just a shiftwork plan (rota).

Errors 1, 2, 3, and 8 appeared to be generated by users who preferred the acquisition of data from figures and charts over text. Errors 4 through 7 appeared to be generated by a lack of adequate instructions and/or pointers on the page.

Information Acquired from Assists

The assists provided by the observer to the participants revealed other weaknesses in the interface design. On the New SF Plan page:

- The concept of available, qualified people who would not be included in the shift schedule was not well explained on the page.
- A question arose about the fact that the Panama plan was available and generated 21 extra people when the number of people available was 81, but when the number of available people was cut by 11, the Panama plan was no longer available. This seemed counterintuitive.
- In SF, some security posts are not manned at all time. How can this variability be reflected in the interface? Discussion with the participant suggested two approaches to the problem. First, the Mission Scheduler Interface could be linked here and used to deal with irregular schedules of elements or sub-elements. Second, instead of dividing an SF squadron administratively into (for example) four flights on solely the basis of macro approaches to day and night scheduling, divide the squadron into elements based on shiftwork demands. For example, a flight or element that deals with nuclear weapon security could work rapidly-rotating, 8-hour shifts with no variability in the number of posts manned. Meanwhile a flight that deals with access control inside the base might be split into three elements that use a split-shift schedule for reduced staffing at night, and a flight that deals with gate security for base access could be split into four elements that use an 8+12 schedule with longer shifts on weekends, when traffic is light. Many variants of these approaches would be available and would be supported by the New SF Plan page.
- In SF, not all personnel are qualified for all duties. How can this variability be reflected in the interface? Probably with the same approaches as above, with unqualified people left out of the employment ratio calculation for the more demanding duties.

- The employment ratio (calculated by a link from the New SF Plan page) may also be called a manning factor.

On the Known Plans page:
- The abbreviations "nil," "ineff" and "Admin" in the table were not interpretable. The table needed a better caption.
- The "Complex" column did not belong in the table. It needed to be moved to a well-labeled, subsequent paragraph.
- The word "interpolated" in the 5-crew plan pop-up was not understandable.
- The word "solution" in the pop-ups was confusing.

On the New Plan page:
- The need to click either the "Cities" or the "Bases" button to allow use of the location drop-down list was not stated on the page.
- The error message (red font) was difficult to detect.
- It was unclear that the Analysis was being produced for only one crew.
- For the Analysis table, there was no instruction to hover over a cell to see the average effectiveness for that shift.
- On the right-hand axis of the Analysis graph, the numbers in the scale for BAC had no decimal points.

On the Additional Information page:
- The relative risk graphs in pop-ups were confusing to one participant, especially the fourth-night effect graph. The heights of the bars did not convey a message that is congruent with the elevation of relative risk. For example, the bar that indicated a 36% increase in risk was four times as tall as the bar that indicated a relative risk of 1.0.
- The shift system pop-up needed a clearer discussion of the relevance and non-relevance of shiftwork system calculations to various potential users. Also, emphasis was needed for the fact that a free day (F) in a system is the same as a day off (O) in a shiftwork plan.
- The importance of the employment ratio calculation was not explained clearly in that pop-up.
- The number of crews graph, in that pop-up, needed axis labeling congruent with the message of demands made upon employee and employer.
- In the shift start-time pop-up, the word "nadir" was difficult to interpret. Also, the first sentence had a typo.
- The discussion comparing slow and fast rotations, in the rotation pop-up, was not as clear as it needed to be to help the user understand that we know very little about which one might be better.

Discussion Questions

Specific comments made by the participants are listed here.

What were your objectives as you tested this interface [after using the first couple of pages]?
The participants provided the following statements in response to this question:
- Ease of use: does the design support the purpose?

- Can the software help me design the best possible schedule and help assure that I have enough people to man it?
- How may I apply this information? Will it provide support material for briefings to the squadron and base commanders?
- Can I navigate with ease? Is the program user-friendly?
- How may I use this program?
- How may the issue of varying qualifications of personnel be addressed?

Was the scope of the usability testing that you did adequate to meet your objectives?

- Yes, but actual use would be more revealing (n = 2).
- Yes (n = 3).
- Better to use a scenario adapted from an actual requirement, such as the security requirement and plan at Lackland AFB. Then, how to move from 12-hour to 8-hour shifts? How to introduce a 5-crew schedule?

Could the Shiftwork Scheduler analysis report be formatted differently to better assist you in scheduling? (n = 4)

- I needed this when I was scheduling shiftwork.
- Add the hover note for the Analysis table.

Could the Shiftwork Scheduler analysis graph be formatted differently to better assist you in scheduling? (n = 4)

- The length of the [28-day] graph was bothersome.
- The graph needs labels on the x-axis.
- Freeze the y-axis labels when scrolling left-right.
- The graph will be good for schedule-change planning and for briefings.

What other improvements should be made to the Shiftwork Scheduler interface?

- The overall format was good.
- The hyperlinks were good.
- The hyperlinks were not preferred, but no alternate approach could be suggested.
- Add Help.
- I needed this when I was scheduling shiftwork 6 years ago.
- Use colors to help draw attention to objectives of relative risk and number of crews graphs.
- Better speed [referring specifically to the loss of connectivity described above]
- Less reading, more visuals.
- Tailor to varying personnel qualifications [and, by extension, to variable staffing of posts].

In response to these questions and recommendations, a Help file was constructed and the following changes were made to the interface:

On the Home Page:

- Text added indicating that the software could not prevent the effect of fatigue on mental performance.

On the New SF Plan page:

- Added a calculator icon
- Added text clarifying the concept of available, qualified people who would not be included in the shift schedule.
- The question about the Panama plan generating 21 extra people when the number of people available was 81, but being no longer available when the number of available people was cut by 11 was resolved as a non-problem. It was due to the correct application of the employment ratio to total number of people.
- Added text that discussed possible shiftwork solutions to the practice of not staffing some security posts at some times, and the problem of not all personnel being qualified for all duties.
- Added text to refer to the employment ratio also as a staffing factor.

In the Employment Ratio Calculator pop-up:

- Added an error check to protect from employment ratio < 1 errors.
- Changed the ratio calculator lines from fixed words to defaulted text boxes.
- Added the calculator icon (above) within this pop up.

On the Known Plans page:

- Removed the abbreviations "nil," "ineff" and "Admin" from the table.
- Moved the "Complex" column from the table to a subsequent paragraph.
- Replaced the word "interpolated" in the 5-crew plan pop-up with "inserted in."
- Defined the word "solution."

On the Additional Information page:

- Added text clarifying that a shiftwork schedule is more than just a shiftwork plan (rota).
- Replaced the relative risk graphs with tables in the pop-ups.
- Added text in the shift system pop-up to clarify the relevance and non-relevance of shiftwork system calculations to various potential users, and to help show that that a free day (F) in a system is the same as a day off (O) in a shiftwork plan.
- Added text to help show the importance of the employment ratio calculation in that pop-up.
- Provided an improved number of crews graph in that pop-up, changing the axis labeling to be congruent with the message of demands made upon employee and employer.
- Modified the text in the shift start time pop-up.
- Modified text comparing slow and fast rotations in the rotation pop-up.

The following tasks were postponed:

- Build a stand-alone version of the interface (no connection to SAFTE engine on server). This version would lack the New Plan page and would be hosted on a SF server.
- Put BAC and relative risk truth tables in examples.

DISCUSSION

REQUIREMENTS ANALYSIS

This discussion focuses on several of the nine components of shiftwork scheduling and refers to several of the nine principles of shiftwork scheduling (Miller, 2006). The first components deal with the number of people available to support 24/7 operations. This was, undoubtedly, the greatest obstacle faced by USAF Security Forces at the time of this requirements analysis session. The next components deal with the management of shiftworkers' time. Finally, Security Forces practices are addressed with respect to the known principles of shiftwork scheduling.

Number of People

On the surface, it appeared that the Security Forces were attempting to use four crews to support 24/7 operations. This would be a good thing. In regular, non-combat 24/7 military operations, the number of crews used should be greater than the number of shifts per day so that at least one crew is off each day. The number of crews sets the work demand in a regular *plan* (not a *schedule*): the number of crews defines the average yearly, weekly, and daily amounts of time worked by an individual. Each year provides (364 days per year x 24 hours per day =) 8,736 hours to be worked in continuous operations. Each crew must work their proportional share of the year. If one specifies four crews, then each person in the crew must work 2,184 hours per year, an average of 42 hours per week. Thus, the 4-crew solution approximates the usual work demand placed on weekday-only workers.

The graph of the relationship between the average amount of time an individual works and the number of crews used is not a straight line (Miller, 2006). Because the line is curved, the 4-crew solution provides the optimal balance between (1) the work, health, social, and safety demands placed upon the shiftworker in terms of hours worked per unit time, and (2) the personnel cost to the employer for safe and productive system operation in terms of the number of crews needed.

The Security Forces were using the 4-crew solution inappropriately because of their general personnel shortage. Irregular schedules were being used to increase the ratio of work days to days off. For example, if a ratio of 6 days on to 3 days off was being used and the security demand increased, the ratio might be changed to 6 days on and 2 days off to meet the new demand. Of course, the most appropriate way to meet the higher demand would be to have Security Forces personnel in reserve who could be used. Unfortunately, irregular schedules often generate morale problems because they violate the shiftwork scheduling principles of predictability, equity and good-quality time off (Miller, 2006).

In addition to having enough people for four crews, the employment ratio (ratio of work to free days) must be great enough to deal with holidays, sick leave, annual leave and other administrative and training time. The total work force needed is the product of the minimum number of people for a single crew, the number of crews required, and the employment ratio.

There are many cases in the military in which training is so demanding of shiftworkers' time that a 4-crew solution seems impractical. A solution to this problem is to use five crews. Typically,

a 5-crew solution is created by adding a 5th crew to a 4-crew solution and placing one crew in a 9-to-5 (or other) schedule for training for a continuous period (Miller, 2006). This option was discussed with the SMEs.

Time Management

There are two solutions that may be applied to the 24/7 scheduling problem: fixed shifts and rotating shifts. With respect to rotating shifts, there are two options: fast and slow rotation. On fixed shifts, the worker always works the same shift: for example, permanent days or permanent nights. Most fixed-shift workers tend to become dissatisfied with fixed shifts and wish to "graduate" to day shifts. Besides obvious inequities for workers between fixed day and night shifts, fixed night-shift workers usually do not keep their day-sleep, night-work schedule on days off. Thus, fixed shift schedules acquire much of the nature of poorly-scheduled rotating shifts.

Many 24/7 operations are supported by rotating shiftwork, in which the worker changes (rotates, as the hands of a clock rotate around the clock face) from one shift to another at some specified interval, be it "fast" or "slow." There are infinite numbers of possible rotating shiftwork plans. The principle-based scheduling approach planned for the F-PAS interface will constrain the infinite number of possible rotating shiftwork plans to those that are practical to implement and least harmful to shiftworker health, job performance and attitude.

In theory, shift length may be any amount of time up through 24 hours. In practice, only the even factors of 24 hours (2, 4, 6, 8, 12 or 24 hours) are useful. The most-debated issue concerning shift length these days concerns the use of 12-h shifts instead of 8-h shifts. In regular schedules, shiftworkers are quick to notice that, due to the work compression afforded by 12-h shifts, they can have longer continuous periods off when working 12-h shifts than when working 8-h shifts. These longer time-off periods are viewed as being of high value, and so shiftworkers often prefer 12-h shifts to 8-h shifts. However, there is well-placed concern about the use of the 12-h shift length when safety issues are present. For example, combined data from three excellent field studies demonstrated that the "…risk [of injuries and accidents] increased in an approximately exponential fashion with time on shift such that in the twelfth hour it was more than double that during the first 8 h" (Folkard and Tucker, 2003). If one were to investigate, for example, accidental firearm discharges within the work shift for Security Forces personnel, controlling for time of day, it is likely that the 9th through 12th hours of the work shift would be overrepresented compared to the 1st through 8th hours.

Shift overlap ("hand off") is the time spent before and after a shift to transition control of the system from the crew ending its shift to the crew starting its shift. Overlap is not used in calculations and comparisons of shiftwork plans because overlap requirements vary only as a function of the work domain. However, overlap must be used for calculations of total numbers of hours worked, after a shiftwork plan has been selected. Often, excessive overlap times are viewed as necessary by management. Unfortunately, these long overlaps extend the workday so much that there is a high risk of cumulative fatigue, followed by chronic fatigue and accompanying morale and retention problems.

Security Forces Practices

As with many military organizations, USAF Security Forces shift work practices are limited by insufficient numbers of SF personnel at most locations. When a unit has a sufficient number of people to staff a standard, 4-crew system, planners tend to use the "Panama" or "every-other-weekend-off" rota in a shiftwork system that uses 12-hour shifts and 7 work days combined with 7 free days per cycle (7W:7F system; the Panama plan is described fully in Miller, 2006). The rotation between day and night shifts usually occurs after two cycles, i.e., once every 28 days (a "slow" rotation). Working days or nights, an individual follows this work-rest sequence for each 14-day cycle: 2 days on, 2 days off, 3 days on, 2 days off, 2 days on, and 3 days off. The series of 3 days on and the series of 3 days off both fall on Friday, Saturday and Sunday, giving an individual every other weekend off. However, the Fridays "off" during a flight's night shift month should be viewed as recovery days. Thus, across 364 days (twenty-six 14-day cycles), an individual has 26 weekends, or 52 weekend days, off per year. That is only half of the number recommended by the shiftwork principles (Miller, 2006). Thus, although the Panama plan is a relatively good 12-hour shiftwork plan (rota), it is weak in this regard and management should expect shiftworkers to perceive inequity with weekday-only workers who have 52 weekends off per year. Table III shows the shift alignment for the 14-day cycle of the Panama plan. Although the equity of this plan could be improved by converting it to a 5-crew plan by placing one additional crew on a weekday-only schedule during each cycle, the lack of a sufficient number of SF personnel probably make this impossible at present. In fact, USAF Security Forces rarely have the luxury of using the Panama plan.

Table III. Shift alignment table for the 14-day cycle of the Panama Plan

	Day						
Week	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**	**Sat**	**Sun**
1	W	W	R	O	W	W	W
2	R	O	W	W	R	O	O
Note: W is a workday (12-h day or night shift with rotation once every 28 days); O is a day off; R is a recovery day if W is the night shift, else it is a day off (O).							

More typically, because insufficient numbers of SF personnel are present at a location, a legacy 6W:3F, 4-crew system with 12-hour shifts is used as a default (DDDDDDOOO or NNNNNNROO, where D is a day shift, N is a night shift, R is a recovery day, and O is a day off). The reason that this is a "legacy" system is that the 6W:3F system is best suited for 8-hour shifts, but SF adopted 12-hour shifts to deal with its personnel shortage. The result of this change is that, instead of having half of the work force covering two shifts per day, as is normal for a system that uses 4-crews and 12-hour shifts, SF uses ¾ of the workforce during each 24-hour period (as one would expect for 8-hour shifts and 4 crews). This practice increased the individual's work demand from the standard 4-crew average workweek of 42 hours to an average of 56 hours per week, the same average work demand experienced by workers in 3-crew systems. Reviewing the shiftwork principles and supporting industrial mishap data, one notes that six nights of work in a row is too much. A rapidly rotating DDDNNNROO plan with 12-hour shifts (still in the 6W:3F system) might be more appropriate in many cases.

Security Force units vary the ratio of work to free days away from 6W:3F within elements and flights as the work demand changes. The numbers of posts that are manned each day also vary as a function of work demand, with low-priority posts being unmanned during periods of high work demand. There are several problems associated with the varying of the W:F ratio. The main problem is that the varying of the ratio to meet transiently increased security demands can lead to *ad hoc* scheduling. As mentioned, above, the resulting irregular schedules can generate morale problems because they violate the shiftwork scheduling principles of predictability, equity and good-quality time off.

Interface Overview

Our general plan for the F-PAS interfaces was to use two main conceptual pathways for scheduling: regular schedules and irregular schedules. Regular schedules for shift workers would be supported by the sequential, prescriptive approach documented in Miller (2006). This approach would generate schedules based on a set of algorithms using inputs such as the number of crews, shift length, shift plan, start date, and start time. Schedules such as the Panama plan would result from this prescriptive approach. Output would consist of a listing of 24-hour periods showing the performance effectiveness for a crew across the 24-hour period using color (green, yellow, red), average performance effectiveness values, and the time and amount of the lowest value for a shift. Tabular output would also be available for import into a spreadsheet.

When too few personnel were available to meet the work demand with a regular schedule, a scheduler would use an irregular schedule to accomplish the required work. Irregular schedules would be created and evaluated using procedures similar to existing FAST™ input methods. This approach was descriptive rather than prescriptive; the user generates the schedule without any constraints and the model is used to evaluate it. Output would be similar to that for Regular schedules. These needs were to be supported by the Mission Scheduler Interface (Eddy et al., 2008).

WALK-THROUGH

The three walks through the developing SSI were informative with respect to interface design. Because there was general ignorance across the Air force with respect to the design of regular, rotating shiftwork schedules (AFIA, 2004), we took a best guess at how to design the interface, basing our guess on the results of the requirements analysis and the information provided in Miller's scheduling manual (2006). The approach was prescriptive, pushing the scheduler toward a 4-crew solution with either 8- or 12-hour shift lengths. The approach was also educational, providing background information in pop-up windows and on the Additional Information page.

The first cut was well received. The major change request was to break the single-page interface into several pages. One interesting innovation that was suggested was the tabular display of cognitive effectiveness for one crew as a function of shifts and days. Another was the selection of the color blue to represent impairment during the pre-dawn hours of the night shift. These and any other changes were made to the interface during its development.

INSPECTION EVALUATION

Generally, the overall ratings of the interface for ease of application performance and overall function were "acceptable" and "very acceptable" (1s and 2s on a scale of 1 to 5, where 1 was best and 5 was worst). The mean amount of time spent on each scenario question ranged from 1.04 min on the *Additional Information* page to 2.15 min on the *New Plan* page. The mean times appeared to agree with the difficulty levels of the pages. The *New Plan* and *New SF Plan* pages were less informational in design and probably required longer decision times than the other pages.

The mean numbers of assists per scenario question ranged from 0.55 to 3.5, with the highest numbers for the *New SF Plan* and *Known Plans* pages, which were related by references to known shiftwork plans. The mean numbers of errors per scenario question ranged from 0.15 to 1.5, with the *Home* and *New SF Plan* pages recording the highest number. Generally, the *New SF Plan* page seemed to generate the most usability problems among the five pages. The descriptions of eight specific errors, our "assists" and the answers to our other usability questions allowed us to design improvements that were needed on the various pages. We created a Help file and made these changes, about 20 in number, just prior to the end of the technical portion of the contract.

CONCLUSIONS

The personnel shortage faced by USAF Security Forces may be representative of many military and civilian groups who must support 24/7 operations. Faced with the lack of adequate numbers of skilled personnel to support the desired 4-crew solution, along with an adequate staffing ratio, organizations are unable to establish acceptable shiftwork schedules. However, part of the problem that SF faced was the absence of policies, procedures and tools that could provide assistance for the development of any reasonably good shiftwork schedule. The requirements assessment revealed the impact of that absence within SF.

If adequate policies, procedures and tools had been available, SF might have realized that the legacy 12-hour, slowly-rotating, 6W:3F system that they adopted was not feasible because it caused too many sequential nights of work for individuals on the night shift. They might have adopted, instead, the superior rapidly-rotating plan suggested, above.

Our iterative sessions with SMEs indicated that the shiftwork scheduler's interface should provide a mechanism that allows schedulers to make schedules that meet the demands of the work, informed decisions with respect to all of the principles and components of shiftwork scheduling, and "what-if" comparisons across various alternative schedules. The comparisons should be made in terms of a specific schedule's compliance with the shiftwork scheduling principles and in terms of points within a schedule that are particularly fatiguing, identified by the SAFTE model. In the latter case, for example, the model should identify the likelihood that an individual beginning the first day shift of a cycle has not fully recovered from previous night work and is, therefore, at an elevated risk of a mishap. The interface should suggest the use of countermeasures when mishap risk is higher than normal.

The input component of the interface should constrain the potentially infinite possibilities for shiftwork schedules to those that make the most sense in terms of the nine shiftwork principles (Miller, 2006). The input component should be both minimal in scope and provide extensive optional guidance with respect to the nine principles and nine components of shiftwork scheduling. The shiftwork scheduling manual (Miller, 2006) should be available for study and review. The output component of the interface should identify clearly the "fatigue points" in the proposed schedule, based upon SAFTE™ calculations, and the compliance of the schedule with the nine principles. The output component should also allow side-by-side comparisons of several candidate schedules. The walk-through and inspection evaluation processes indicated that most of these requirements were met reasonably well and that potential users were able to operate the interface easily.

REFERENCES

Air Force Inspection Agency. *Shift Worker Fatigue*. Eagle Look PN 04-602, Air Force Safety Center, Kirtland AFB, NM, May 2004.

Bailey RW (1997). Usability studies and testing. Chapter 12 in TS Andre and AW Schopper, *Human Factors Engineering in System Design*, CSERIAC SOAR 97-03, Defense Technical Information Center, Fort Belvoir, MD.

Eddy DR, Hursh SR (2001). *Fatigue Avoidance Scheduling Tool (FAST)*. (AFRL Technical Report No. AFRL-HE-BR-TR-2001-0140). Brooks AFB, TX: Human Effectiveness Directorate Biodynamics and Protection Division, Flight Motion Effects Branch.

Eddy DR, Hursh SR (2006). *Fatigue Avoidance Scheduling Tool (FAST™) Phase II SBIR Final Report, Part 2*. (AFRL Technical Report No. AFRL-HE-BR-TR-2006-0040). Brooks City-Base, TX: Human Effectiveness Directorate, Biosciences and Protection Division, Fatigue Countermeasures Branch.

Eddy DR, Moise SL, Miller JC, Smith R (in press). *24/7 Operational Effectiveness Toolset: Mission Scheduler Interface*. Technical Report, Contract FA8650-06-C-6606, Air Force Research Laboratory, Brooks City-Base, TX.

Folkard S, Tucker P. Shift work, safety and productivity. *Occupational Medicine*, 53(2):95-101, 2003.

Foret J, Lantin G (1972). The sleep of train drivers: an example of the effects of irregular work schedules on sleep. In W. P. Coquhoun (Ed.), *Aspects of Human Efficiency* (pp. 273-282). London: The English Universities Press.

Hursh SR, Redmond DP, Johnson ML, Thorne DR, Belenky G, Balkin TJ, Storm WF, Miller JC, Eddy DR (2004). Fatigue models for applied research in warfighting. *Aviat Space Environ Med, 75*(3, Suppl.): A44–53.

Miller JC (2006). *Fundamentals of Shiftwork Scheduling*. (AFRL Technical Report No. AFRL-HE-BR-TR-2006-0011). Brooks City-Base, TX: Human Effectiveness Directorate, Biosciences and Protection Division, Fatigue Countermeasures Branch. (ADA446688)

Miller JC, Eddy DR, Moise SL (2008). *24/7 Operational Effectiveness Toolset: Usability Assurance Plan*. Technical Report, AFRL-RH-BR-TR-2008-0052, Contract FA8650-06-C-6606, Air Force Research Laboratory, Brooks City-Base, TX.

Pollard JK (1996). *Locomotive Engineer's Activity Diary. Final Report*, (DOT/FRA/RRP-96/02, DOT-VNTSC-FRA-96-12). U.S. Department of Transportation, Federal Railroad Administration, Office or Policy and Program Development and Office of Research and Development, Washington, D.C. 20590.

Reid K, Roach G, Dawson D (1997). The proportion of time spent sleeping and working across the day in train drivers working irregular hours. *Sleep Research*, *26*.

APPENDIX A: F-PAS SHIFTWORK SCHEDULER USABILITY QUESTIONNAIRE

NTI, Inc., April 2008

Years of active duty: ____
Years spent in shiftwork and/or night work as worker and/or scheduler: _____
FAST user? Yes No (circle one)

Overall Ratings

Please rate the ease of application of the Shiftwork Scheduler interface to the intended task: the simplicity with which the Shiftwork Scheduler interface can be employed to help with scheduling. In an ideal world, the interface would be totally natural and predictable in behavior. Nothing should obstruct your progress in completing this task.

Very acceptable (1) (circle one)
Acceptable (2)
Borderline (3)
Unacceptable (4)
Very unacceptable (5)

Rate the performance of the Shiftwork Scheduler interface: the speed with which the interface responds to requests.

- Very acceptable (1) (circle one)
- Acceptable (2)
- Borderline (3)
- Unacceptable (4)
- Very unacceptable (5)

Rate the support information for the Shiftwork Scheduler interface: the information available to acquire, use and support the Shiftwork Scheduler interface. Encompasses initial instructions, user guides, tutorials, integrated assistance.

- Very acceptable (1) (circle one)
- Acceptable (2)
- Borderline (3)
- Unacceptable (4)
- Very unacceptable (5)

Rate the Shiftwork Scheduler interface's function: the overall capabilities of the Shiftwork Scheduler interface.

- Very acceptable (1) (circle one)
- Acceptable (2)
- Borderline (3)
- Unacceptable (4)
- Very unacceptable (5)

Please discuss with the observer:

- What were your objectives as you tested this interface?
- Was the scope of the usability testing that you did adequate to meet your objectives?
- Could the Shiftwork Scheduler analysis report be formatted differently to better assist you in scheduling?
- Could the Shiftwork Scheduler analysis graph be formatted differently to better assist you in scheduling?
- What other improvements should be made to the Shiftwork Scheduler interface?

APPENDIX B: NTI F-PAS SHIFTWORK SCHEDULER TOOL USABILITY DATA

Data:

On a separate page, keep orderly, transcribable notes of the **pathways** the participants take, **problems** participants have and what participants **say** as they work. Definitions for the table, below:

- *Number of subtask assists: When the participant cannot proceed on a subtask, the observer gives direct procedural help to allow the test to proceed.*
- *Number of subtask errors: Instances where test participant had to attempt portions of the task more than once.*
- *Number of subtask reversals: Number of times participant had to "back up" to find something on a previous page that they needed on the current page.*
- *Subtask completion (Y/N): Yes = complete and correct achievement of subtask goal.*
- *Problem severity (0/1/2):* 0 = no problem; 1 =minor (users are annoyed, but this does not keep them from completing the scenario); 2 = show stopper (if we don't fix this, users will not be able to complete the scenario; and/or many users will be frustrated, and they may give up).

Subtask	# Assists	# Errors	# Reversals	Severity	Completion
1. Start time at Home page:	NA	NA	NA	NA	NA
2. Q1. Will the Shiftwork Scheduler generate a 24/7 plan that prevents the effects of fatigue on mental performance? (No)				0 1 2	Yes No
3. Q2. The four main secrets to shiftwork scheduling include: (Worker satisfaction, Having enough people)				0 1 2	Yes No
4. Q3. When should fatigue countermeasures be used? (At predicted fatigue points)				0 1 2	Yes No
5. End time:	NA	NA	NA	NA	NA
6. Start time at New SF Plan page:	NA	NA	NA	NA	NA
7. Q4. Use the Employment Ratio Calculator. If there are 10 holidays, 14 vacation days, 14 sick days, 24 training days, and 60 deployment days allotted per year, 15 people are needed per crew, and 4 crews are needed, a. What is the employment ratio? (1.34); b. How many people do you need? (81)				0 1 2	Yes No
8. Q5. Close the Employment Ratio Calculator. You have 81 people available, 15 posts to be manned and an employment ratio of 1.34. For the Panama plan, how many people will not be on the shiftwork schedule at any given time? (21) If your manning is cut 10% to 73 people, can you still use the Panama plan? (No)				0 1 2	Yes No
9. End time:	NA	NA	NA	NA	NA
10. Start time at the Known Plans page:	NA	NA	NA	NA	NA

Subtask	# Assists	# Errors	# Reversals	Severity	Completion
11. Q6. If you wish to implement the DDNNOOOO plan, a. What is the shift length? (12 hours) b. How many crews do you need? (4)				0 1 2	Yes No
12. Q7. If you wish to use a 5-crew plan so that one crew is always in training or accomplishing administrative duties, what kind of a plan would you use as a basis for building the 5-crew plan? (4 Crew Plan)				0 1 2	Yes No
13. Q8. If you have a complex schedule with a low work demand at night and, thus, need only half as many people working at night, what kind of plan might meet your needs? (Split Crew)				0 1 2	Yes No
14. Q9. If you have a complex schedule with a low work demand on weekends and, thus, may use a longer shift length on weekends, what kind of plan might meet your needs? (8+12 Plan)				0 1 2	Yes No
15. End time:	NA	NA	NA	NA	NA
16. Start time at New Plan page:	NA	NA	NA	NA	NA
17. Q10. Refer to the Known Plans page to get the shift sequence from the Metropolitan rota. Sequence: (DDSSNNOO) Enter this sequence on the New Plans page. Use 1 April 2008 as a start date, 07:00 as a start time, Kelly AFB as the location, and no shift overlap. Click on the "Analysis" button. a. What is the lowest mental performance for the first night shift? (71%) b. What is the average mental performance for the first night shift? (76%) (hover the cursor over the cell) c. Should fatigue countermeasures be applied during this shift for safety sensitive jobs? (Yes) d. What is the basis for a job being labeled as "safety-sensitive?" (risk to the public)				0 1 2	Yes No
18. Q11. Close the Analysis page and refer again to the New Plan page. Change the shift length to 12 hours (don't change anything else). Click on the "Analysis" button. What happens? (Error: 12-hr plans don't have swing shifts)				0 1 2	Yes No
19. Q12. Enter one 28-day cycle of the Panama plan sequence from the Known Plans page on the New Plan page. That full cycle is DDOODDDOODDOOONNOONNNOONNOOO. Use 1 April 2008 as a start date, 07:00 as a start time, Kelly AFB as the location, and a 1-hour shift overlap. Click on the "Analysis" button. a. What is the lowest mental performance for the second day shift? (78%) b. What is the average mental performance for the second day shift? (81%) (hover the cursor over the cell) c. What is the lowest BAC equivalent reached on the last night shift? (0.008)				0 1 2	Yes No
20. Q13. Close the Analysis page and refer again to the New Plan page. The Analysis page that was displayed was for how many crews? (1)				0 1 2	Yes No

Subtask	# Assists	# Errors	# Reversals	Severity	Completion
21. Q14. Does the Shiftwork Scheduler show you how many days should elapse between one crew starting the cycle and another crew starting the cycle? (No)				0 1 2	Yes No
22. End time:	NA	NA	NA	NA	NA
23. Start time at Additional Information page:	NA	NA	NA	NA	NA
24. Q15. During what part of the normal circadian rhythm are speed and accuracy above average? (07:00 to 19:00)				0 1 2	Yes No
25. Q16. What percentage of accident risk elevation occurs during the night shift compared to the day shift? (30%)				0 1 2	Yes No
26. Q17. What percentage of accident risk elevation occurs on the fourth night shift compared to the first night shift? (36%)				0 1 2	Yes No
27. Q18. When cognitive (mental) effectiveness is 78%, what is the equivalent a. BAC? (0.05%) b. Industrial accident risk? (1.28)				0 1 2	Yes No
28. Q19. In one word, what is shiftwork scheduling principle number 7? (Equity)				0 1 2	Yes No
29. Q20. In shiftwork system analysis, what does a. W mean? (Work period) b. F mean? (Free period)				0 1 2	Yes No
30. Q21. What is a useful shiftwork system for four crews and 12-hour shifts? (2nW:2nF)				0 1 2	Yes No
31. Q22. In the notation for a shiftwork plan (rota), a. D means (DAY) shift b. S means (SWING) shift c. N means (NIGHT) shift d. O means (OFF) shift				0 1 2	Yes No
32. Q23. A shiftwork schedule is simply a shiftwork plan (rota). (False)				0 1 2	Yes No
33. Q24. The relationship between the average number of hours worked by a crew and the number of crews is a straight line. (False)				0 1 2	Yes No
34. Q25. The optimal number of crews to use in terms of demands on both the employer and employee is (4)				0 1 2	Yes No
35. Q26. In two words, the importance of calculating the employment ratio accurately is to assure what? (Number of people needed)				0 1 2	Yes No
36. Q27. A slow rotation is superior to a fast rotation in terms of safety and productivity. (False)				0 1 2	Yes No
37. Q28. A "forward" rotation means that a crew rotates to a shift that starts (later) on the clock.				0 1 2	Yes No

Subtask	# Assists	# Errors	# Reversals	Severity	Completion
38. Q29. Concerning shift length, the risk of an accident in the 12th hour of a shift is (2.2) times greater than during the first eight hours of the shift.				0 1 2	Yes No
39. Q30. Shift overlap is not used in calculations and comparisons of shiftwork plans. (True)				0 1 2	Yes No
40. Q31. Shift differentials may be provided by adjusting the numbers of hours worked on different shifts. (True)				0 1 2	Yes No
41. Q32. What scheduling principle is supported when the shiftwork plan is aligned to provide the highest possible number of weekend days off? (Number 5)				0 1 2	Yes No
42. Q33. If the shift start time is selected carefully, then both (day) and (swing) shift workers will have the opportunity to get a good night of sleep.				0 1 2	Yes No
43. Q34. Night workers are often at risk for (driving) accidents after work.				0 1 2	Yes No
44. End time:	NA	NA	NA	NA	NA

Comments: