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MITRE TECHNICAL REPORT

Human Performance and Fatigue Research for Controllers—Revised

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Abstract

Fatigue has been on the National Transportation Safety Board (NTSB) "Most Wanted List" since the initial list in 1990 and remains a topic of active investigation to this day. The focus of this document was air traffic controller fatigue. This focus is reflected in the review of ongoing and past research results as well as a plan to address gaps in this research.

A literature search was conducted using multiple terms directly and indirectly associated with fatigue. These terms were then applied across multiple databases. Additionally, direct outreach was conducted to identify current research that would not yet be reflected in the literature.

The results of the literature review and outreach are separated into three areas: 1) research that used air traffic controllers (ATCs) as participants and investigated factors influencing fatigue in controllers, fatigue's effects on performance in controllers, and/or the effects of fatigue countermeasures for controllers; 2) a synthesis of the knowledge in the area of fatigue and air traffic control (ATC) including the original research discussed in area 1 , as well as information gained from previous literature reviews, books, pamphlets, reports, and other research that did not use controllers as participants; and 3) models to predict controller fatigue.

Gaps identified during the literature review and outreach and recommendations to fill the gaps are presented. The gaps were prioritized based on the estimated risk to safety in the National Airspace System (NAS) from highest to lowest. The first priority is to quantify air traffic controller fatigue and the second is to validate measures of air traffic controller performance sensitive to fatigue. The third priority is to explore, develop, and if appropriate, validate tools for individualizing shift schedules. The fourth priority focuses on collecting data to support and implement a sleep disorder policy. The fifth and final priority is to develop and validate a fatigue model for ATCs.

Ancillary material is presented in a series of appendices. Specifically, the literature review was expanded to include studies of aircrew fatigue in both civilian and military aircrews and the results are presented. Additionally, relevant fatigue research from comparable environments is discussed. These environments include security surveillance, military command and control, process control, and medical practice. Basic research studies on vigilance, cognitive, and psychomotor measures are reviewed. A review of existing models to measure and analyze fatigue risk as well as an evaluation of modeling techniques from both civilian and military applications is included. A discussion of short-term fatigue countermeasures and Fatigue Risk Management Systems used in comparable environments is included. Subjective and objective measures of fatigue are reviewed as well as workload, situational awareness, boredom, monotony, motivation, and stress.

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1 Introduction

The National Transportation Safety Board (NTSB) has had fatigue on its "most wanted" list since the adoption of the original list in September 1990. The Federal Aviation Administration (FAA) has initiated a rapid response Aviation Rulemaking Committee (ARC) on fatigue to propose changes to flight time/duty time rules for pilots. Additionally, the FAA Office of Fatigue Risk Management along with the National Air Traffic Controllers' Association (NATCA), are formulating recommendations to mitigate fatigue's effect on air traffic controller performance. The FAA's definition of fatigue is:

> "Fatigue is a condition characterized by increased discomfort with lessened capacity for work, reduced efficiency of accomplishment, loss of power or capacity to respond to stimulation, and is usually accompanied by a feeling of weariness and tiredness" (Salazar, G. J., 2007).

To provide a starting point for future applied research pertaining to air traffic controllers (ATCs), The MITRE Corporation (MITRE): 1) analyzed existing research to review what is known about the effect of fatigue on air traffic controller performance, 2) identified gaps in knowledge, and 3) developed a plan to fill those gaps. This report documents efforts in all three areas.

2 Gap Analysis

The information gathering for the gap analysis is described in section 2.1, the results in 2.2, and models to predict controller fatigue in 2.3.

2.1 Information Gathering

MITRE first conducted a literature review and outreach to organizations that sought research that measured air traffic controller fatigue in objective and subjective terms, assessed the effect of fatigue on controller performance (including the effect of fatigue on the commute to and from work), modeled controller fatigue, or assessed or investigated the effectiveness of fatigue countermeasures used by controllers. The priority was to identify studies of current United States (U.S.) civilian controllers, as well as U.S. military controllers handling U.S. civilian aircraft in the National Airspace System (NAS). This is due to differences in work practices and work environment between the U.S. and other countries. For example, the practice of dynamic resectorization that New York Air Route Traffic Control Center (ARTCC) employs is not used in Europe. Additionally, while facilities the U.S. are generally dim, the Europeans work in brighter environments (FAA, 2009a; EUROCONTROL, 2010). Differences in techniques for traffic flow management also exist. For instance, Europe deals with demand management months in advance through capacity and slot control , while the U.S. deals with it day-by-day as needed with ground delay programs and/or Air Traffic Flow Management Regulations (Performance Review Commission and the Air Traffic Organization Strategy and Performance Business Unit, 2009). Differences in productivity (Europe was 44% less productive in terms of flight-hours per controller in 2002) exist due to the ease of coordinating with the military in the U.S. compared to in Europe (where there are 34 different military departments) and due to the FAA's staff planning (Cleaz-Savoyen, 2004). Studies involving ATCs from foreign countries were also examined and summarized collectively.

Following completion of the gap analysis, major gaps in controller-related fatigue knowledge were identified and prioritized. Recommendations for future studies were subsequently developed with subject matter experts across MITRE and are presented in section 3.

Given changes in air traffic control (ATC) systems over time (e.g., introduction of User Request Evaluation Tool (URET) and beginning roll-out of En Route Automation Modernization (ERAM)) current research was of greatest interest. Fatigue research from a decade after the August 5, 1981 firing of 11,345 striking ATCs was also of greater interest than data prior to that date since a decade was required for staffing levels to return to normal without initial replacements of nonparticipating controllers such as supervisors, staff, and military controllers.

2.1.1 Literature Search

MITRE conducted a literature search using the terms in Table 2-1. This list was compiled based on the methodology described in the previous section, and as such, was limited to research focused on fatigue that used ATCs as participants. Databases searched included the American Institute of Aeronautics and Astronautics (AIAA), Defense Technical Information Center (DTIC) (public reports, formerly STINET), Engineering Village (Compendex and Inspec), FAA, Google Scholar, National Aeronautics and Space Administration (NASA), National Technical Information Service (NTIS), NTSB, PubMed, Science Direct, Transport Canada, United States Department of Transportation, and Web of Knowledge.

Table 2-1. Literature Search Terms

Air Traffic Control (ATC)
Air Traffic Management
Air Route Traffic Control Center (ARTCC)
Causal or contributing factors in accidents and incidents
Circadian rhythm
Controller
Fatigue
Fatigue countermeasures
Fatigue measurement
Fatigue model development and validation
Fatigue predictors
Fatigue risk management
Field tests
Laboratory studies
Operational characterization
Performance measures
Physiological indicators
Radar Approach
Risk to aviation
Shift work
Sleep
Sleep deprivation
Sleep disorders
Sleep loss
Stress
Sustained operations
Time on task
Terminal Radar Approach Control (TRACON)
Workload

2.1.2 Outreach

This effort focused on recent and current research as a priority, therefore, MITRE reached out to the organizations listed in Table 2-2 to identify current, on-going, and unpublished research.

Table 2-2. Outreach

Aerospace Medical Association
Air Force Safety Center
Army Aeromedical Research Laboratory
Article 55 Working Group Fatigue Risk Management System
Aerospace Systems Technical Group
Austrian Society for Sleep Medicine and Sleep Research
European Aviation Safety Agency (EASA)
German Society for Sleep Research and Sleep Medicine
National Institute for Occupational Safety and Health (NIOSH)
North American Rail Alertness Partnership
Royal Air Force School of Aviation Medicine
Transport Canada Civil Aviation (TCCA)

Due to the small number of identified research efforts regarding the effect of fatigue on controller performance, the literature search was expanded to include studies regarding the effects of fatigue on performance and commuting of aircrew and of shift-workers in environments similar to ATC. Similar environments included security surveillance, military command and control, process control, and medicine. The results of the expansion can be found in Appendices A (aircrew) and B (comparable environments). In addition, basic research on vigilance, cognition, and psychomotor skills was reviewed and can be found in Appendix C.

The limited research on modeling controller fatigue and predicting the effect of fatigue on performance as a function of task and environment and the effectiveness of countermeasures led to an expansion to models to predict fatigue in general and can be found in Appendix D.

The shortage of information on fatigue countermeasures used by ATCSs in the U.S. and abroad led to a review of airlines, energy, maritime, medicine, rail, and space and can be found in Appendix E.

2.2 Results of the Literature Review and Outreach

The literature review identified presentations, reports, and articles regarding research on fatigue and ATCs. The results of the literature review and outreach are split into two sections. Section 2.2.1 contains information regarding research that investigated fatigue and used ATCs as participants. Section 2.2.2 synthesizes the knowledge in the area of fatigue and ATCs and contains the original research discussed in section 2.2.1, as well as literature reviews, books, pamphlets, reports, and other research that did not utilize ATCs as participants.

Through outreaching to other organizations, MITRE identified a current fatigue research effort on sleep, fatigue, and alertness being conducted by NASA, the FAA and NATCA. Data collection is completed and the next steps are analysis and comparison of the survey and objective data (Orasanu et al., 2010).

2.2.1 Identified Controller Fatigue Research

The section reviews original research which employed ATCSs as participants. Research topics include factors that influence fatigue in controllers; the effects of fatigue on controller performance; and countermeasures to fatigue in controllers.

2.2.1.1 Research on Factors Influencing Fatigue and on Fatigue and Performance

The original research identified during the literature search as being related to factors that influence or to the effects of fatigue on performance are presented in Table 2-3.

In 1999, the Civil Aerospace Medical Institute received funding from Congress to investigate shiftwork issues related to ATCSs in response to the concerns regarding the effects of fatigue on performance. As a result, three projects were undertaken.

The first was a survey aimed at assessing fatigue associated with controller's shifts. Known as the Nation-wide Shiftwork & Fatigue Survey, the survey was distributed to all series 2152 Air Traffic Control Specialists (ATCSs) (approximately 21,000). The survey itself was a modified version of the Standard Shiftwork Index (SSI) and is available in Appendix F.

The second project was a field study conducted at a Terminal Radar Approach Control (TRACON) and an ARTCC. Known as the Air Traffic Shiftwork and Fatigue Evaluation (AT-SAFE), it lasted 21 days and collected data on sleep, mood, fatigue, and cognitive performance to assess how shift times and time off between shifts were associated with these factors. Over a period of 21 days, Wrist Activity Monitors (WAMs) were worn by 71 Full Performance Level (FPL) controllers and logs where reports of sleep duration and quality, as well as Positive Negative Affect Schedule (PANAS) mood ratings and Stanford Sleepiness Scale (SSS) sleepiness ratings were kept. On days 2-14 of the study, the complete CogScreen Aeromedical Edition battery was completed by the participants at the beginning, three hours into, and at the end of their shift.

The third project was a laboratory simulation of common air traffic controller shifts including clockwise and counter-clockwise rotations. As the participants were not ATCSs, results from this project will not be included in this report.

Table 2-3. Studies on Factors Influencing Fatigue and on Fatigue Effects on Performance in Controllers

Title	Purpose/Scope/ Objective	Participant Info (analyzed)	Equipment/Data Collected/Measures	Study Information	Conclusions
Part of the Nation-Wide Shiftwork & Fatigue Survey					
Cruz, C. E., D. J. Schroeder, A. J. Boquet, 2005, "The Relationship of Age and Shiftwork to Sleep, Fatigue and Coping Strategies in Air Traffic Controllers," Poster Presentation, 76th Scientific Meeting of the Aerospace Medical Association, May 5-8, 2005, Kansas City, MO.	Assessed relationship between age and aspects of sleep, fatigue, and health.	3247 Certified Professional Controllers (CPCs), unspecified	Modified SSI • Age • Body Mass Index (BMI) • Total sleep time • Sleep quality • Sleep disturbances • Coping strategies • Chronic fatigue	Survey/Questionnaire • Sent out to >21,000 series 2152 ATCS • 6,712 returned the survey (29% response rate) • 3,247 were CPCs and included age	Age and poorer sleep and fatigue were not associated consistently. • Ages 31-45 reported highest chronic fatigue levels, poorest sleep quality, and shortest sleep time before a morning shift • BMI and sleep disturbances were seen to increase with age up to 55 (where it dropped off likely because of smaller numbers of controllers in the older age group). Good coping strategies increased with age.

Cruz, C., A. Boquet, C. Hackworth, K. Holcomb, T. Nesthus, 2004, "Gender and Family Responsibilities as They Relate to Sleep and Fatigue Responses on the FAA Air Traffic Control Shiftwork Survey," Poster Presentation, 75th Annual Scientific Meeting of the Aerospace Medical Association, May 3-7, 2004, Anchorage, AK.	Assessed the relationship between gender and family responsibilities and sleep, fatigue, and domestic disruption.	2,879 CPCs, unspecified	Modified SSI
			• Total sleep time
			• Sleep quality
			• Chronic fatigue
			• Domestic disruption
			• Presence of children <13 years old in home
				Survey/Questionnaire
				• Sent out to >21,000 series 2152 ATCS
				• 6,712 returned the survey (29% response rate)
				• 2,879 were CPCs, between 18 and 50 years old
				  • 2423 male
				  • 456 female
					Compared to CPCs without children < 13 years, CPCs with children < 13 years old reported higher chronic fatigue levels, poorer sleep quality, less sleep time on days off, and higher domestic disruption.
					• 1.4x more likely to have higher chronic fatigue
					• 1.6x more likely to have poorer sleep quality
					• ~12 min less sleep time on off days
					• 3.0x more likely to have high domestic disruption
					• Indicate that the findings regarding chronic fatigue, and sleep quality may not be operationally significant.
					
					Compared to males, females reported higher chronic fatigue and greater sleep time.
					• 1.5x more likely to have higher chronic fatigue
					• ~18 min more sleep time on off days
					• Indicate that the findings regarding

Title	Purpose/Scope/ Objective	Participant Info (analyzed)	Equipment/Data Collected/Measures	Study Information	Conclusions
					chronic fatigue may not be operationally significant. Compared to males with children < 13 years, females with children < 13 years reported more domestic disruption. • 2.4x more likely to have domestic disruption. Conclude that having young children likely is more important than gender when looking at sleep, fatigue, and domestic variables.

Nesthus, T. E., C. Cruz, A. Boquet, C. Hackworth, May 3, 2004, "Risk Factor for Air Traffic Control Specialists Commuting to and From Early Mornings and Midnight Shifts," Poster Presentation, 75th Annual Scientific Meeting of the Aerospace Medical Association, May 3-7, 2004, Anchorage, AK.
 	
Nesthus, T., C. Cruz, C. Hackworth, A. Boquet, June 2006, *An Assessment of Commuting Risk Factors for Air Traffic Control Specialists*, DOT/FAA/AM-06/13, Office of Aerospace Medicine, Federal Aviation Administration, Washington, D.C.
	Investigated risk factors for accidents/incidents driving to and from work.	6712 controllers, unspecified	Modified SSI
			• Mental sharpness
			• Commute distance
			• Roadway type (i.e. highway, country roads, city traffic)
				Survey/Questionnaire
				• Sent out to >21,000 series 2152 ATCS
				• 6,712 returned the survey (29% response rate)
				
				Study split respondents into CPCs (Terminal/En Route) or Flight Service Station (FSS) categories.
					Commute distance of >20 miles increased chance for lapses of attention, falling asleep, and near-misses while commuting at least 2x across all respondents.
					• FSS: 2.3-5.4x
					  ◦ Greatest risk for lapses of attention and falling asleep was seen for country roads and early morning shifts.
					
					• CPCs: 2.1-3.0x
					  ◦ Greatest risk for lapses of attention and falling asleep was seen for city traffic and afternoon shifts.
					
					Mental sharpness was rated lowest at the end of the midnight shift for all participants.
					
					Low self-reported mental sharpness was associated with increased lapses in attention.
					• For FSS highest risk was at the beginning and end of early-morning shifts.
					• For CPCs, the highest risk was at the end of eerily morning, afternoon, and midnight shifts.

Title	Purpose/Scope/ Objective	Participant Info (analyzed)	Equipment/Data Collected/Measures	Study Information	Conclusions
Part of AT-SAFE Field Study					

Nesthus, T. E., A. R. Dattel, K. Holcomb, 2005, "Test-Battery Performance Associated with Age, Shift Schedule and Quick-Turn Rotations for a Sample of Air Traffic Controllers," Poster Presentation, 76th Scientific Meeting of the Aerospace Medical Association, May 5-8, 2005, Kansas City, MO.	Observed the difference in performance for shifts with >16 hours off and <12 off as well as how age affected performance.	70 Full Performance Level (FPL) controllers, TRACON and ARTCC	Performance including accuracy, response time and correct completions per minute on CogScreen-Aeromedical Edition subtasks
			• Divided-Attention Dual Task Indicator
			• Divided-Attention Sequence Comparison
			• Dual-Task Tracking
			• Dual-Task Previous Numbers
				Field Study
				21 days
				
				Within-subjects variables
				• Shift
				  • Early morning v. afternoon
				• Time of test
				  • Before shift v. ≥ 4 hours into shift
				Between-subjects variables
				• Age
				  • < 40 v. ≥ 40
					• Quickturns lead to decreased performance, especially before a night shift
					• Performance in the older population was effected more so

Nesthus, T.E., L. Dobbins, J. T. Becker, P. Della Rocco, 2001, "Shiftwork-Related Changes in Subjective Fatigue and Mood for a Sample of Air Traffic Control Specialists," (Briefing), Aerospace Medical Association 72nd Annual Scientific Meeting, May 6-10, 2001, Reno, NV.	Assessed how ATC shift start times affected quantity and quality of sleep; and mood and fatigue.
	• Early morning - a shift starting before 8a.m.
	• Day – a shift starting between 8:00a.m. – 9:59a.m.
	• Midday - a shift starting between 10:00a.m.-12:59p.m.
		71 FPL controllers, TRACON and ARTCC	Logs
			• Sleep duration
			• Sleep quality ratings
			• PANAS mood ratings
			• Stanford Sleepiness Scale (SSS) sleepiness ratings
			
			Wrist Activity Monitor (WAM)
			
			Cognitive performance
			• CogScreen-Aeromedical
				Survey/Questionnaire Field Study
				
				21 days
				• 1: practice and other cognitive testing, training, modified Shiftwork Index
				• 1-21: WAM and logs
				• 2-14: Complete battery of CogScreen tests
				  • At the beginning, 3 hours into, and end of the shift
					Sleep duration
					• Early morning ~5.8 hrs
					• Day ~6.5 hrs
					• Midday ~7.7hrs
					• Afternoon ~7.5 hrs
					• Midnight ~2.3 hrs
					  • After midnight ~4.5 hrs
					• RDO (regular day off) and AL (annual leave) ~7.8, ~7.3 hrs
					
					Sleep quality corresponded with sleep duration, that is, less sleep generally resulted in poorer quality ratings.
					
					Positive mood ratings were generally higher after sleep before the shift compared to after the shift. Lowest ratings corresponded to

Title	Purpose/Scope/ Objective	Participant Info (analyzed)	Equipment/Data Collected/Measures	Study Information	Conclusions

	• Afternoon - a shift starting between 1:00p.m.-7:59p.m.
	• Midnight - a shift starting between 8:00p.m.-1:00a.m.
			Edition subtests
			• Other various cognitive tests
			
			Modified SSI
					early morning and midnight start times, which were associated with lower sleep duration and quality. Negative mood ratings stayed an average of 12 regardless of day/start time.
					
					Sleepiness ratings
					• Early morning
					  • Preshift: ~3
					  • Postshift: ~3
					  • Drive home: ~3
					  • After arriving: ~3
					• Day
					  • Preshift: ~2.5
					  • Postshift: ~3.5
					  • Drive home: ~3.5
					  • After arriving: ~3.5
					• Midday
					  • Preshift: ~2
					  • Postshift: ~3
					  • Drive home: ~3
					  • After arriving: ~3.1
					• Afternoon
					  • Preshift: ~2
					  • Postshift: ~3.5
					  • Drive home: ~3.3
					  • After arriving: ~3.5
					• Midnight
					  • Preshift: ~2.75
					  • Postshift: ~4.5
					  • Drive home: ~4.75
					  • After arriving: ~4.9

Nesthus, T. E., C. Cruz, A. Boquet, L. Dobbins, K. Holcomb, 2003, "Comparisons of Sleep	Assessed how quickturns affected quantity and quality of sleep; and mood	71 FPL controllers, TRACON and ARTCC	Logs • Sleep duration • Sleep quality ratings	Survey/Questionnaire Field Study 21 days	• Quickturns reduced total sleep time • For the afternoon to early morning quickturn, positive affect ratings decreased and negative rating increased

Title	Purpose/Scope/ Objective	Participant Info (analyzed)	Equipment/Data Collected/Measures	Study Information	Conclusions
Duration, Sleep Quality, Mood, & Fatigue Ratings During Quick-Turn Shift Rotations for Air Traffic Control Specialists," Poster Presentation, 74th Scientific Meeting of the Aerospace Medical Association, May 4-9, 2003, San Antonio, TX.	and fatigue. Additionally, it assessed the effects of varying time off between quickturns (8, 9 or 10 hours).		• PANAS mood ratings • SSS sleepiness ratings Wrist Activity Monitor (WAM) Cognitive performance • CogScreen-Aeromedical Edition subtests • Other various cognitive tests Modified SSI	• 1: practice and other cognitive testing, training, modified Shiftwork Index • 1-21: WAM and logs • 2-14: Complete battery of CogScreen tests • At the beginning, 3 hours into, and end of the shift	• For the early morning to night shift quickturn, SSS ratings increased • For the early morning to night quickturn, 9 hours instead of 8 between shifts resulted in higher PA and better sleep quality sleepiness • For the afternoon to early morning quickturn, 9 hours instead of 8 between shifts resulted in better mood and sleep quality, and reduced sleepiness
Nesthus, T.E., K. Holcomb, C. Cruz, A. Boquet, L. Dobbins, J.T. Becker, 2002, "Sleep Duration, Subjective Fatigue, and Mood Reported During Four Workshift Schedules," (Briefing), Aerospace Medical Association 73rd Annual Scientific Meeting, May 5-9, 2002, Montreal, Canada.	Assessed how 4 shift schedules affected quantity and quality of sleep; and mood and fatigue. Schedules looked at included • 2-2-1(2 afternoons, 2 early mornings, 1 midnight); • 2-1-2 (2 afternoons, 1 midday, 2 early mornings); • 2-3 (2 afternoons, 3 early mornings); • SS-EM (5 straight early mornings)	44 FPL controllers, TRACON and ARTCC	Logs • Sleep duration • Sleep quality ratings • PANAS mood ratings • SSS sleepiness ratings Wrist Activity Monitor (WAM) Cognitive performance • CogScreen-Aeromedical Edition subtests • Other various cognitive tests	Survey/Questionnaire Field Study 21 days • 1: practice and other cognitive testing, training, modified Shiftwork Index • 1-21: WAM and logs • 2-14: Complete battery of CogScreen tests • At the beginning, 3 hours into, and end of the shift	Sleep Duration was seen to be a function of shift start time. • 2-2-1: Day 1 ~8.5 hrs; Day 2 ~7.5 hrs; Day 3 ~5.75 hrs; Day 4 ~6 hrs; Day 5 ~2 hrs; RDO 1 ~8 hrs; RDO 2 ~9.5 hrs • 2-1-2: Day 1 ~8 hrs; Day 2 ~7 hrs; Day 3 ~7.5 hrs; Day 4 ~6 hrs; Day 5 ~6 hrs; RDO 1 ~7.75 hrs; RDO 2 ~8 hrs • 2-3: Day 1 ~8 hrs; Day 2 ~8 hrs; Day 3 ~5.75 hrs; Day 4 ~6 hrs; Day 5 ~6 hrs; ~8 on RDO1 and 2 • SS-EM: Day 1 ~6 hrs; Day 2 ~6 hrs; Day 3 ~6.5 hrs; Day 4 ~6.5 hrs; Day 5 ~6.5 hrs; ~7 on RDO1 and 2 Sleep quality had a significant day main effect. Generally it declined throughout the work week and improved on the weekends. • 2-2-1: Declined days 1-3, improved on day 4, declined again on day 5, and then

Title	Purpose/Scope/ Objective	Participant Info (analyzed)	Equipment/Data Collected/Measures	Study Information	Conclusions

	Where
	• Early morning being a shift starting before 8a.m.
	• Midday being a shift starting between 10:00a.m.-12:59p.m.
	• Afternoon being a shift starting between 1:00p.m.-7:59p.m.
	• Midnight being a shift starting between 8:00p.m.-1:00a.m.
			Modified SSI		improved
					• 2-1-2: Increased days 1-3 (slightly), decreased slightly days 4 and 5 and improved on the weekend
					• 2-3: Declined days 1-4, improved day 5 and through the weekend
					• SS-EM: Improved day 2, decreased day 3, hovered days 4-5 and the first RDO, increased on RDO 2
					
					Better mood was seen on the 2-1-2 as compared to all other shift schedules. All shifts saw a general decline across the work week.
					
					SSS ratings increased post shift, potentially due to circadian rhythm.
					• 2-2-1
					  • Preshift: Increased days 1-3, steady days 3-5
					  • Postshift: steady days 1-3, decreased day 4, increased greatly day 5
					• 2-1-2
					  • Preshift: steady days 1-3, creased days 4-5
					  • Postshift: decreased days 1-3, increased slightly day 4, decreased minimally day 5
					• 2-3
					  • Preshift: decreased day 2, increased day 3, decreased day 4, increased day 5
					  • Postshift: decreased day 2, increased slightly day 43, decreased day 4, steady day 5
					• SS-EM
					  • Preshift: steady days 1-3, decreased day 4, increased day 5

Title	Purpose/Scope/ Objective	Participant Info (analyzed)	Equipment/Data Collected/Measures	Study Information	Conclusions
					• Postshift: decreased day 2, increased day 3, decreased slightly day 4, steady day 5
Becker, J.T., T. E. Nesthus, R. Caldararo, P. Della Rocco, 2001, "The Effects of Shiftwork and Fatigue on Cognitive Function Among Air Traffic Control Specialists," (Briefing), Aerospace Medical Association 72nd Annual Scientific Meeting, May 6-10, 2001, Reno, NV. Becker, J. T., R. Caldararo, J. Luther, T. E. Nesthus, 2002, "Effects of Sleep Loss and Wake Hours on Cognitive Function Among Air Traffic Controllers," (Briefing), Aerospace Medical Association 73rd Annual Scientific Meeting, May 6-9, 2002, Montreal, Canada. Becker, J. T., R. Caldararo, J. Luther, T. E. Nesthus, 2002, "Normal Age-Associated Neuropsychological Performance Variation Among Air Traffic Control Specialists," (Briefing), Aerospace Medical Association 73rd Annual	Assessed the effect of different schedules on cognitive performance.	70 FPL controllers, TRACON and ARTCC	Cognitive performance • CogScreen-Aeromedical Edition subtests • Other various cognitive tests Neuropsychological tests • general abilities • memory and learning • info processing speed • visual and auditory simple and divided attention Logs • Sleep duration • Sleep quality ratings • PANAS mood ratings • SSS sleepiness ratings Wrist Activity Monitor (WAM) Modified SSI	Survey/Questionnaire Field Study 21 days • 1: practice and other cognitive testing, training, modified Shiftwork Index • 1-21: WAM and logs • 2-14: Complete battery of CogScreen tests • At the beginning, 3 hours into, and end of the shift	• Cognitive performance was seen to be affected by age. • Sleep loss impacted performance more toward the middle and end of the shift. • Subjective alertness and age were observed to be viable predictors of the controllers' info processing speed and working memory scores.

Title	Purpose/Scope/ Objective	Participant Info (analyzed)	Equipment/Data Collected/Measures	Study Information	Conclusions
Scientific Meeting, May 6-9, 2002, Montreal, Canada.					
All other studies					

Rhodes, W., I. Szlapetis, K. Hahn, R. Heslegrave, K. V. Ujimoto, 1994, *A Study of the Impact of Shiftwork & Overtime on Air Traffic Controllers -Phase I: Determining Appropriate Research Tools and Issues*, TP 12257E, Transportation Development Centre (TDC), Montreal, Quebec.
 	
Helsgrave, R. J., W. Rhodes, I. Szlapetis, K. Ujimoto, H. Moldofsky, 1995, "Impact of Shiftwork and Overtime on Air Traffic Controllers: Subjective Estimates of Performance Deficits as a Function of Shift, Chronobiological Typology and Age, " Abstract, *Sleep Research*, Vol. 25, p. 101.
	Aimed to identify potential future simulation, laboratory and field research.
	
	Investigated physical, psychological, and social effects of shiftwork and overtime on controllers.
		921 Canadian controllers, unspecified	Survey
			• Performance deterioration rating at the end of 8 hour and 12 hour shifts on a 1 to 6 scale.
			• Commuting and falling asleep information.
			• Coping strategies
			• Social factors
			• Health
			• Sleep information
			
			Semi-structured interviews
			• Coping strategies
			• Social factors
			• Health
			• Sleep information
			• Performance
			• Job satisfaction
			
			Diary
			• Sleep/Work/Leisur e data
			
			Walter Reed Performance Assessment Battery (PAB)
			• Spatial, memory, perceptual and
				Survey
				• Sent out to 1836 controllers (all in system)
				• 921 returned the survey (over 50% response rate)
				
				Semi-structured interviews
				• Based on survey questions to allow for elaboration and verification
				• 26 completed
				
				Diary
				• Two types pilot tested
				  • Descriptions of work, social and leisure activities recorded every 15 min – completed by 2 controllers
				  • Common activities were coded and controllers recorded their activities over 24 hour periods – completed by 5 controllers
				
				PAB
					Survey Data
					Performance change on scale of 1(normal performance) to 6 (severely impaired)
					• 12-hour shift: 3.6
					• 8-hour shift: 2.05
					• 8-hour midnight shift: 3.6
					• 8-hour midnight overtime shift: 5.0
					
					Falling asleep on commute
					• Controllers who had not worked midnights in the previous year: 16%
					• Controllers working 1-4 consecutive midnights: 27%
					• Working 5 consecutive midnights: 32%
					• Working 6 consecutive midnights: 40%
					• Working 7 consecutive midnights: 60%
					
					Ability to cope with shiftwork with age
					• 25-29: 30% found coping slightly more difficult.
					• 35-39: 52% found coping slightly more difficult, 38% found coping much more difficult.
					• 40-44: 43% found coping slightly more difficult, 42% found coping much more difficult.
					
					Performance change after a 8 hour midnight shift taking into account age saw the greatest performance change on the midnight shift with those over 35 having an average rating of 3.9, and those younger having an average rating of 2.9.

Title	Purpose/Scope/ Objective	Participant Info (analyzed)	Equipment/Data Collected/Measures	Study Information	Conclusions
			cognitive skills PSG • Sleep and physiological measures	• Piloted to assess its usefulness for monitoring effects of fatigue over time. PSG • Completed by 2 controllers	Self-report sleep • Controllers working low density towers reported more sleep • Average of 5 hrs of poor sleep on midnight shifts regardless of age • Less sleep with age **Diary** • Diary with activity codes provided more complete information compared to open-ended • Conclusions were not drawn due to small sample **PAB** • Conclusions were not drawn due to small sample • Showed potential use for monitoring effects of fatigue for future research **PSG** • Helped to identify the need to research the effects of different schedules on performance
Rhodes, W., R. Heslegrave, K. V. Ujimoto, K. Hahn, S. Zanon, A. Marino, K. Côté, I. Szlapetis, S. Pearl, 1996, *Impact of Shiftwork and Overtime on Air Traffic Controllers - Phase II: Analysis of Shift Schedule Effects on Sleep, Performance, Physiology and Social Activities*, TP 12816E, Transportation	Investigated the effects of different shift schedules on sleep, cognitive performance, health, and activities on days off.	30 Canadian controllers from centres and towers working • MMMMM • EEDDM • ESDMN (full protocol) 20 Canadian controllers,	Performance • PAB Subjective sleep • SSS on PAB Fatigue • Fatigue Scale on PAB Sleep quality and	Field Study Full protocol • Sleep monitoring during problem times identified in Phase I • PSG monitoring during work • Performance tests 3x each shift – beginning, middle and end	Controllers were observed to get less sleep while sleeping during the day or evening compared to at night. Controllers got 25-30% less sleep during the work week compared to on their days off. The sleep quality was also poorer. Slow wave sleep (SWS) and rapid eye movement (REM) sleep onset was earlier and SWS was increased. Cognitive performance was greatly reduced

Title	Purpose/Scope/ Objective	Participant Info (analyzed)	Equipment/Data Collected/Measures	Study Information	Conclusions
Development Centre (TDC), Montreal, Quebec.		controllers from centres and towers working any of the three shift cycles above as well as • EEDDD • DDDEE (partial protocol) M= midnight E= evening D= day S= Swing N= late evening/early midnight	quantity • PSG • Activity logs Alertness • PSG Circadian Rhythm • Melatonin in urine	• Urine collected in the 24 hours around the monitored sleep • Activity logs for 13 days Partial protocol • Performance tests 3x each shift – beginning, middle and end • Activity logs for 13 days	at the end of the EEDDD and DDDEE cycles; attributed to accumulated sleep debt. Cognitive performance on midnight shifts was attributed to an accumulated sleep debt, little sleep prior to the midnight shift and the effects of the circadian rhythm. Additionally, PSG recordings indicated microsleeps and inattention. Midnight shifts had a poor diet. Melatonin collection indicated that circadian rhythms did not adapt to schedules and remained day/night oriented. Controllers over 35 were seen to get less sleep compared to younger controllers.
Luna, T.D., J. French, J. L. Mitcha, K. J. Neville, 1994, *Forward Rapid Rotation Shiftwork In USAF Air Traffic Controllers: Sleep, Activity, Fatigue and Mood Analyses*, AL/CF-TR-1994-0156, Armstrong Laboratory, Crews Systems Directorate, Brooks Air Force Base, TX. Luna, T. D., J. French, J.L. Mitcha, J. L., 1997, "A Study of USAF Air Traffic Controller Shiftwork: Sleep, Fatigue, Activity, and Mood Analyses," *Aviation, Space, and Environmental*	Investigated sleep, circadian rhythm, fatigue, activity, mood and performance for ATCs working forward rapid rotations.	Military controllers, RAPCON and tower 13: sleep, temp, sub. Fatigue 12: POMS 9: actigraphs	Subjective sleep • Sleep log Objective sleep and general activity level • Actigraph Temperature • Oral thermometer Fatigue • School of Aerospace Medicine Fatigue Scale Mood • Profile of Mood States (POMS)	Field Study 2 and a half shift rotations • Sleep log after any sleep • Temp every 4 hours • Fatigue scale every 4 hours • POMS midway through every shift • NovaScan™ B midway through every shift	Sleep on duty • Significantly more sleep was seen on the night shift compared to day or swing shifts. • The average amount of sleep on the night shift indicated by the actigraph was 85 minutes, while the average amount indicated in the log was 26 minutes. • Discrepancy likely due to not wanting to report sleeping on shift. Sleep off-duty • Restfulness and quantity of sleep was greatest after a swing sift and significantly greater than that after a day shift. Fatigue and Mood • Fatigue levels were greatest on the night shift (compared to day and swing).

Title	Purpose/Scope/ Objective	Participant Info (analyzed)	Equipment/Data Collected/Measures	Study Information	Conclusions

Medicine, Vol. 68 No. 1, pp. 18-23.			Cognitive performance
			• NovaScan™ B computerized performance test
					• Fatigue, Vigor, and Confusion were greatest on the night shift.
					  • RAPCON experienced more confusion and vigor than tower.
					
					Temperatures indicated that all participants' (temperature) circadian rhythm remained diurnally oriented.
					
					Performance
					• There were insufficient rails for a full analysis, however, learning was seen to be impaired on the night shift (compared to day and swing).
					
					Comparison with controls
					• Sleep after duty (subjective)
					  • Control group: avg. 7.9 hours of sleep
					  • ATCs avg.: 7.6 hours of sleep after a swing shift; 5.4 after a day; 6.3 after a night.
					• POMS
					  • Control group: no significant differences across shifts.
					  • Fatigue, vigor, and confusion significantly higher on night shift.

Rokicki, S. M., Oct 1982, *Fatigue Workload, and Personality Indices of Air Traffic Controller Stress during an Aircraft Surge Recovery Exercise*, SAM-TR-82-31, USAF School of Aerospace Medicine, Aerospace Medical Division, Brooks Air Force Base, TX.	Explored fatigue, workload and personality traits during a four day surge recovery exercise.	22 military controllers, unspecified	Sleep • School of Aerospace Medicine Fatigue Scale Fatigue and Workload • Crew Status Survey Personality	Survey/Questionnaire 4 consecutive days Beginning of each day • School of Aerospace Medicine Fatigue Scale • Crew Status Survey • Parts 1 and 2 of STPI	Participants obtained an average of 7 hours of sleep each night, with 90% having little or no trouble falling asleep, 65% feeling moderately rested upon wakening, and 70% feeling they needed more sleep. The highest fatigue levels were seen at the end of the first day, and the lowest were seen at the end of the last. While the average score pointed to a level shy of moderate fatigue, there was a wide range of individual scores

Title	Purpose/Scope/ Objective	Participant Info (analyzed)	Equipment/Data Collected/Measures	Study Information	Conclusions
			• State-Trait Personality Inventory (STPI) (parts 1 and 2) • Part 1: current level of anxiety, curiosity and anger traits • Part 2: long-term level of anxiety, curiosity and anger traits	Before exercise, after exercise, and end of day • Crew Status Survey • Part 1 of STPI *On day 2: completed only 3x (unspecified) *On day 4:completed only 2x (beginning and end of the day)	(1 - 6 on a 7 point scale). The average workload stayed below a 4 rating ('challenging, but manageable'), but again had a wide range (1 - 6 on a 7 point scale). Anxiety was greatest at the beginning of day 1 and right before the first exercise of day 1 and returned to normal state levels by the end of day 4.
Schroeder, D., R. Rosa, L. Witt, 1995, *Some Effects Of 8- Vs. 10-Hour Work Schedules On The Test Performance/Alertness Of Air Traffic Control Specialists*, DOT/FAA/AM-95/32, Office of Aviation Medicine, Federal Aviation Administration, Washington, D.C. Schroeder, D. J., R. R. Rosa., L. A. Witt, 1998, "Some Effects of 8- vs. 10-Hour Work Schedules on the Test Performance/Alertness of Air Traffic Control Specialists," *International Journal of Industrial Ergonomics*, Vol. 21, No. 3, pp. 307-321.	Investigated performance differences between 8 hour and 10 hour shifts	52 En Route ATCs	Computerized National Institute of Occupational Safety and Health (NIOSH) Fatigue Test Battery Objective • Choice reaction time • Mental arithmetic • Grammatical reasoning Subjective • Sleep quality • Sleep quantity • Mood • Somatic complaints Naval Psychiatric Research Unit mood scale • mood	Field Study 3 weeks	There was no significant difference in performance between the 2-2-1 schedule and 4 10 hour days.

Title	Purpose/Scope/ Objective	Participant Info (analyzed)	Equipment/Data Collected/Measures	Study Information	Conclusions
Signal, T. L., P. H. Gander, Sept 2007, “Rapid Counterclockwise Shift Rotation in Air Traffic Control: Effects on Sleep and Night Work," *Aviation, Space, and Environmental Medicine*, Vol. 78, No. 9, pp. 878-885.	Examined sleep and sleep loss pattern relationship between sleep, duty factors and psychomotor performance	28 ATCs at main radar center in NZ	Sleep • Actigraph • Sleep diaries Performance • Psychomotor Vigilance Test (PVT)	Field Study 4 eight-day data collection for each controller, conducted over an 8 month period	Sleep decreased for ATCs through the work week. ATCs got an average of 2.2 hours of sleep before a midnight shift.

2.2.1.2 Studies on Fatigue Countermeasures

The studies identified during the literature search as being related to fatigue countermeasures are presented in Table 2-4.

Table 2-4. Studies on Fatigue Countermeasures

Title	Purpose/Scope/ Objective	Participant Info (Analyzed)	Equipment/Data Collected/Measures	Study Information	Conclusions
Signal, T. L., P. H. Gander, H. Anderson, S. Brash, 2009, "Scheduled Napping as a Countermeasure to Sleepiness in Air Traffic Controllers," *Journal of Sleep Research*, Vol. 18, Issue 1, pp. 11–19.	Evaluated the effect of a 40-min nap opportunity on performance and alertness on the night shift Assessed the ability of the controllers to nap Examined association between sleep structure and performance/alertness	28 ATCs at main radar center in NZ	Sleep • PSG • Actigraph • Sleep diaries • Questionnaire Performance • PVT	Field Study 4 eight-day data collection for each controller, conducted over an 8 month period	Average sleep time was 19 min on the early shift (22:30-06:00) and 20 on the late shift (23:30-6:30). No REM sleep was observed. Nap reduced spectral power and likelihood of slow rolling eye movements during last hour of shift. Nap improved performance but was not enough to preserve performance throughout shift.
Della Rocco, P. S., C. Comperatore, L. Caldwell, C. Cruz, Feb 2000, *The Effects of Napping on Night Shift Performance*, DOT/FAA/AM-00/10, Office of Aviation Medicine, Federal Aviation Administration, Washington, D. C.	Assessed if naps affected sleepiness and performance on the night shift	59 military and civilian controllers, unspecified	Physiological • EEG, EOG, EMG • actigraph Performance • Modified Bakan Vigilance Test • Air Traffic Scenarios Test (ATSAT) Subjective sleepiness/mood • SSS • Positive and Negative Affect Schedule Other • Sleep/meal/activity logs	Laboratory Simulation 4 days 3 [nap condition] v. 2 [gender] v. 3 [session] • No nap v. short nap (45 min.) v. long nap (2 hours) • Male v. female • Beginning of shift v. right after nap v. end of shift	• Performance on the Bakan vigilance test increased post nap for both nap conditions, with the 2 hour nap resulting in better post nap performance. • "…suggests that naps taken during the midnight shift could be useful as a countermeasure to performance decrement and sleepiness on the midnight shift." (pg. i)

2.2.2 Synopsis of the Body of Knowledge

Using the original research with controllers listed in the previous section, as well as other resources identified during the literature search, (i.e. reviews, books, studies not using ATCSs as participants) a synopsis of the body of knowledge on fatigue and ATCSs is presented.

An expanded discussion regarding the objective and subjective measures of fatigue can be found in Appendix G.

2.2.2.1 Factors Influencing Controller Fatigue and their Effects on Performance

Research has identified work, non-work, and biological related factors that influence sleep and fatigue in ATCSs. See Table 2-5 for a summary of these factors.

Table 2-5. Factors Influencing ATC Sleep and Fatigue[1]

Work-Related Factors	Non-Work-Related Factors
shiftwork	sleep disorders
shift length (time on task)	family responsibilities
type of work being performed	social and leisure engagements
workload	emotional stress
work environment (heat, noise, light and humidity levels)	Individual factors (personality characteristics, health, diet)
Break frequency and length	age
night shifts	circadian rhythms

2.2.2.1.1 Work-Related Factors

Shift work. The majority of ATCSs in the U.S. work rotating shifts schedules between 8 and 10 hours in length (see Table 2-6 for common shift cycles in the U.S. and Table 2-7 for information on work hours; shift length and shift cycles for countries around the world). Rotating shifts result in workers working throughout their circadian rhythm, including during the nadir, when humans are programmed to be asleep. Literature suggests that sleep disturbances caused by shift work can increase fatigue, reduce sleep, and negatively impact performance leading to less than optimal safety conditions for the NAS (i.e. Luna, 1997; Nesthus, Cruz, Boquet, Dobbins, and Holcomb, 2003; van den Heuvel, Fletcher, Paradowski, and Dawson, 2003).

[1] Sources: Marcil and Vincent, 2000; EUROCONTROL, 2007; McCulloch, Baker, Ferguson, Fletcher, Dawson, 2008; Costa 2009

Table 2-6. Air Traffic Controller Schedules[2]

Schedule	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Permanent Shift							
Week 1-3	700-1500	700-1500	700-1500	700-1500	700-1500	Off	Off
Slow Rotation							
Week 1	700-1500	700-1500	700-1500	700-1500	700-1500	Off	Off
Week 2	1500-2300	1500-2300	1500-2300	1500-2300	1500-2300	Off	Off
Week 3	2300-700	2300-700	2300-700	2300-700	2300-700	Off	Off
Rapid Rotation							
Counterclockwise	1500-2300	1500-2300	700-1500	700-1500	Off	Off	2300-700
Clockwise	700-1500	700-1500	1500-2300	1500-2300	2300-700	Off	Off

Table 2-7. Country Norms[3]

Country	Work Hours	Shift Length	Shift Cycles
USA	40h/wk; 5x8h days	≤ 10h	≤ 6 consecutive shifts w/ ≥1day off
Canada	36h/wk over 12 months	6-11h	3 consecutive days off between cycles
UK	40h/wk; 5x8 days	≤8h	Variable; usually 6 on, 4 off
Spain	40h/wk; 120 h/month; max of 1200h/yr	6-12h; 14h at small facilities	Usually 3 on, 3 off or 4 on, 4 off
Germany	38.5 h/wk; 5x7.7h days including breaks	≤10h	4 on, 2 off, or 5 on, 3 off
Netherlands	38h/wk	7-8h	5 on, 2 off; max 9 on, 2 off in the 38h/wk
Switzerland	35h/wk; 7x5h days; max 220 days/yr	7-9h; 10h in towers	Usually 4 on, 2 off; 114-117 rest days/yr; 20 must be on the weekend; min of 8 days off/month

Data from the AT-SAFE field study revealed that sleep quality corresponded to sleep duration, with less time associated with poorer quality ratings. Sleep duration was seen to be least prior to midnight shifts (starting between 8p.m.-1a.m.) with an average 2.3 hours and prior to early morning shifts (starting before 8a.m.) with an average 5.8 hours of sleep, and most prior to midday shifts (starting between 10a.m.-12:59p.m.) with an average of 7.7 hours. Positive mood ratings (measured with the PANAS) were overall were higher before a shift compared to after.

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[2] Adapted from Calvaresi-Barr, 2009; Luna et al., 1994; Signal, 2002

[3] Adapted from: van den Heuvel, C., A. Fletcher, M. Paradowski, D. Dawson, Sept 2003, A Review of Fatigue Management Research Literature and Current Air Traffic Control Practices for AirServices Australia, Edu.au Pty. Ltd.

The lowest ratings were seen for midnight and early morning shifts, while negative mood ratings were approximately an average of 12 throughout the field study, regardless of start time. Sleepiness ratings on the SSS were generally higher postshift compared to preshift and were the highest after the midnight shift at an average rating of 4.5. SSS ratings were also recorded for the drive home and upon arrival home, with the highest scores being on the drive home from the midnight shift (~4.75) and after arriving home from a midnight shift (~4.9) (Nesthus, Dobbins, Becker, and Della Rocco, 2001).

An assessment of the data regarding quickturns (from the AT-SAFE data) noted that all quickturns reduced total sleep time. The same assessment also found that just one more hour off between quickturns could make a difference. For example, 9 hours off resulted in higher positive affect scores and better sleep quality for the early morning to night quickturn; and nine hours instead of eight resulted in higher positive affect ratings, better sleep quality, and reduced sleepiness for the afternoon to early morning quickturn (Nesthus, Cruz, Boquet, Dobbins, Holcomb, and 2003). Cognitive performance data collected at the same time but reported elsewhere found quickturns to lead to decreased cognitive performance, particularly before a night shift (Nesthus, Dattel, and Holcomb, 2005).

In another manipulation of the data obtained from the AT-SAFE field study, the amount of sleep obtained by controllers was compared to mental sharpness. Shift schedules that were examined included: 1) counterclockwise, rapidly rotating schedules without midnights (CR); 2) counterclockwise, rapidly rotating schedules with Midnights (CRM); 3) straight 5s (S5) where controllers worked the same shift for five days; with the shift changing each week; and 4) straight shifts (SS) where controllers worked the same shift throughout the field study (this group was used as a control group). (Della Rocco, Ramos, McCloy, and Burnfield, 2000).

As part of this data manipulation, mental sharpness was assessed as a performance measure. Results indicated that controllers rated their mental sharpness lowest at the beginning of the early morning and midnight shifts (with the rating even lower at the end of these shifts). These shifts were also associated with the lowest average sleep prior to the shift, with an average of 6.5 hours before the early morning and an average of 3.6 hours before the midnight (Della Rocco, Ramos, McCloy, and Burnfield, 2000). .

In the first phase of a study of ATCs in Canada that investigated the effect of overtime and shift work on performance, as part of a larger survey, 921 controllers rated their change in performance at the end of both an 8 hour shift and a 12 hour shift of a scale from 1 (normal performance) to 6 (severely impaired). Ratings from the controllers indicated worse performance on 12 hour shifts (3.6) compared to 8 (2.05). Additionally, controllers rated their performance after an 8 hour midnight shift to be the same as their performance after a 12 hour day or evening shift (3.6); and performance change on an overtime midnight shift was rated 5. Information regarding commuting was also collected. Compared with 16% of controllers who had not worked a midnight shift in the previous year, 27% of controllers who had worked 1 to 4 consecutive midnight shifts in the previous year reported falling asleep while commuting to work. The greater number of consecutive midnights shifts increased the percent of those falling asleep – with 5 consecutive midnights at 32%, 6 at 40% and 7 at 60% (Rhodes, Szlapetis, Hahn, Heslegrave, and Ujimoto, 1994; Helsgrave, Rhodes, Szlapetis, Ujimoto, and Moldofsky, 1995).

For the second phase of the Canadian study, the effects of the different shift schedules worked by controllers on sleep, performance, health, and weekend activities were investigated. 30 controllers were monitored with a polysomnogram (PSG) during selected shifts and off time throughout their work week, they also completed cognitive performance tests, along with fatigue and sleepiness ratings, at the beginning, middle and end of their shifts, kept an activity log for 13 days and had their melatonin levels monitored. Additionally, 20 controllers kept the activity logs and completed the performance tests with sleep and fatigue ratings. Controllers participating in the full protocol either worked five consecutive midnight shifts (MMMMM); two evening shifts, two day shifts, and a midnight shift (EEDDM); or an evening shift, swing shift, day shift, midnight shift, and a night/early midnight shift (ESDMN). Controllers participating in the partial protocol worked any of the three aforementioned shift schedules, or two evenings and three days (EEDDD); or three days and two evenings (DDDEE) (Rhodes, Helsgrave, Ujimoto, Hahn, Zanon, Marino, Côté, Szlapetis, and Pearl, 1996).

The data collected showed that overall, controllers obtained 25 to 30% less sleep during their work week compared to on their weekends. Controllers working the MMMMM schedule were observed to have an average loss of ten hours of sleep by the end of their work week. The amount of sleep obtained by controllers during the day or evening was less than sleep obtained at night. Also, data collected showed that cognitive performance was considerably poor at the end of the EEDDD and DDDEE shifts, which was attributed to an accumulated sleep debt. Performance on the midnight shift was shown to be the poorest (a decrement of between 5 and 10 percent), with the worst performance recorded at the middle of the shift, around three AM, which is during the circadian nadir. PSG recordings indicated microsleeps and prolonged intervals of inattention. These findings was attributed to accumulated sleep debt, little sleep prior to midnight shifts, and the effects of the circadian rhythm, which was not seen to shift or adjust to varying schedules (as determined by monitoring melatonin levels) (Rhodes, et. al., 1996).

Whether clockwise or counter-clockwise rotations have advantages over each other is a continuous debate, with conflicting evidence. Contrary to previous studies, a 2003 study determined that there was no difference between the two types of schedules in regards to sleep disruption and fatigue (Cruz, Detwiler, Nesthus, and Boquet, 2002) and another found no difference between the two in terms of complex and vigilance task performance (Cruz, Boquet, Detwiler, and Nesthus, 2002). Both studies suggested that regardless of the direction of rotation, early morning and midnight shifts resulted in the most problems for these variables (Cruz, Detwiler, Nesthus, and Boquet, 2002; Cruz, Boquet, Detwiler, and Nesthus, 2002). More recently however, a study concluded that the counter-clockwise rapidly rotating schedule did cause sleep disturbances, manifested in less sleep each night resulting in a sleep debt (Signal and Gander, 2007). In a 2006 literature review evaluating shiftwork in ATC for EUROCONTROL, it was concluded that there is no best shift system for ATC, as too many factors play a role (Arnvig et al., 2006).

Task Complexity. Complexity has traditionally been defined subjectively by the controller (Athènes, Averty, Puechmorel, Delahaye, and Collet, 2002). Currently, complexity of traffic is measured as the number of aircraft a controller is willing to accept in a sector, and is determined by the number of aircraft in the sector compared to the sector capacity (Puechmorel and

Delahaye, 2009). Capacity as measured through the number of aircraft in a sector is a crude method of identifying controller workload. For radar controllers along with capacity, the structure of traffic and the geometric features of the sector should be taken into account. Controller workload has two facets, intrinsic complexity related to the traffic structure, and the human factor related to the controller's ability and alertness (Puechmorel and Delahaye, 2009). How do complexity and workload interact? Answering this question will help develop guidelines to improve sector configuration and traffic flow and help to create automation tools and procedures to reduce controller workload (Athènes et al., 2002; Puechmorel and Delahaye, 2009). Much of the research on complexity focuses primarily on ATC workload for radar controllers. Continued research is needed on complexity and workload measurement in radar and other controller positions.

Workload. High or low traffic volume and repetitive tasks may lead an individual to feel fatigued (Marcil and Vincent, 2000) (see Appendix H). In a study that measured fatigue, workload and personality traits during a surge recovery exercise, average workload over the four day exercise stayed below a rating of four that was 'challenging, but manageable' and average fatigue was a level shy of moderate fatigue. However, individual ratings of these variables ranged from 1-6 on 7 point scales.

Performance. As part of a collaboration between NASA Ames Research Center's Fatigue Countermeasures Program and FAA's Civil Aerospace Medical Institute (CAMI)'s shift work and fatigue research program, the Aviation Safety Reporting System Database was searched by NASA to find incidents related to fatigue. Two searches of the 56,589 reports were conducted with 19 keywords. 153 reports (2.7% of all ATC-related reports) were identified through the 19 keywords and included reference to controller fatigue in the narrative (Della Rocco, 1999). CAMI searched the Operational Error/Deviation System (OEDS) as part of this collaborative effort. They assessed the relationship between operation errors/deviations and shift schedules. They examined 3,222 operational errors (OEs) from ARTCC and TRACONs. Among the findings were that 80% of these errors happened when traffic was high (between 8a.m.and 7p.m.) and that 50% of the errors were within the first 30 minutes of a controller being on position. Unfortunately, assessments regarding shift and fatigue factors could not be drawn as there was not sufficient information regarding exposure and traffic volume (Della Rocco, 1999).

2.2.2.1.2 Non-Work-Related Factors

Individual Factors. Personality characteristics can influence an individual's ability to cope with shiftwork and manage fatigue (Marcil and Vincent, 2000). Those who identify themselves as evening types function better during evening and night shifts and cope better with shiftwork overall compared to those who identify as morning types. Controllers who eat well and exercise cope better with fatigue (Marcil and Vincent, 2000).

Age. There is evidence that suggests shiftworkers become less resistant to stress and more susceptible to fatigue due to disruptions to their circadian rhythms and increased sleep disturbances as they age (Costa, 2009). In the U.S. there is the age 56 rule and in Germany older workers work a reduced shift length and have increased break length and are generally reassigned to lower workload positions (van den Heuvel et al., 2003).

Regarding the relationship between age and fatigue in ATCSs, a survey study of 3,247 Certified Professional Controllers (CPCs) was unable to discern a consistent association between age and fatigue. Of the controllers surveyed, ages 31 to 45 reported the highest chronic fatigue levels, poorest sleep quality and shortest sleep time before a morning shift (Cruz, Schroeder, Boquet, 2005).

Data collected during the larger AT-SAFE field study were used to look at performance changes associated with age. Using cognitive performance data collected from 70 FPL controllers from TRACONs and ARTCCs, performance was shown to be affected by age. Additionally, subjective alertness and age were observed to be viable predictors of the controllers' info processing speed and working memory score (Becker, Caldararo, Luther, and Nesthus, 2002).

In the survey study on Canadian controllers, the controllers were asked if it was harder for them to cope with shiftwork as they aged. Eighty percent of those 35 years and older of the 921 who responded found coping with shiftwork to be harder as they got older, and controllers over 35 rated a greater change in performance compared to controllers younger than 35 on 8 hour day evening and midnight shifts (Rhodes et al., 1994; Helsgrave et al., 1995). In the second phase of the study, data collected indicated that those controllers over 35 obtained less sleep compared to their younger colleagues (Rhodes et al., 1996).

Family Responsibilities. Data collected during the Nation-Wide Shiftwork and Fatigue Survey showed that family responsibilities affected sleep and fatigue. Data from 2,879 CPCs indicated that those who had children younger than 13 in the home reported higher chronic fatigue levels, poorer sleep quality, and less sleep on days off (though it noted that findings may not be operationally significant due to odds ratios. While the study had expected to see gender have a large influence on these variables, it concluded that the presence of young children likely had a greater influence on sleep, fatigue, and domestic variables (Cruz, Boquet, Hackworth, Holcomb, Nesthus, 2004).

Sleep Disorders. As a major cause of fatigue is sleep disorders, information on the prevalence of sleep disorders among U.S. ATCSs was sought but not obtained; therefore, sleep disorders that manifest symptoms of fatigue and their prevalence in the general population are discussed in Appendix I.

Further, during the information gathering stage of this project, details of a case regarding a controller with sleep apnea in Australia was obtained. An approach controller in Australia was identified as possibly having a sleep disorder after investigation into two losses of separation. The controller was then diagnosed with moderate to severe OSA and lost his job. As a result, the controller, supported by the union, brought an unfair dismissal case against their former employer. After assessment of the employee by a sleep medicine researcher, recommendations were made that the OSA was enough of a risk to have warranted the dismissal, but that if it was successfully treated, should allow for a return to work and a return to approach control work if compliance and success with therapy could be demonstrated. The court instructed the employer to take the controller back with a protocol in place to monitor treatment. The controller had to purchase a continuous positive airway pressure (CPAP) machine that recorded compliance data so that it could be verified by the employer every two weeks. The controller was also required to have a Maintenance of Wakefulness Test (MWT) every six months for two years and then annually after that. Non-compliance with the CPAP treatment or a MWT score that indicated excessive daytime sleepiness was considered grounds for dismissal. The controller returned to ATC duty, but not to approach controlling, which was a mutual decision between the controller and employer (D. Dawson, personal communication, 2010).

2.2.2.2 Fatigue Countermeasures in ATC

Scheduling. Three of the factors that contribute to workplace fatigue are: working against the circadian rhythm; the duration and workload of shifts as well as the number of breaks during a shift; and working without enough restorative prior sleep. The time for sleep opportunity; breaks and naps during work; and regular, overtime, emergency and on-call schedules that are in line with psychological principles must all be incorporated when managing fatigue risk, but of these, time for sleep opportunity was said to be the most important as shiftwork allows for sleep debt accumulation and generally does not allow for recovery sleep to be obtained during the work week. A minimum 10 hours off between shifts has been suggested for a worker to have 7 to 8 hours of sleep. There is also scientific evidence highlighting the need to have breaks end when sleep will be possible according to the circadian rhythm (van den Heuvel et al., 2003).

The frequency of breaks needs to be dynamic and change according to workload. Scheduling practices also need to be dynamic and change according to current available research on the subject. Napping can compensate for fatigue and increase performance, but sleep inertia and the feasibility of incorporating naps into the work environment needs more investigation. 200 mg of caffeine taken 30 minutes before driving after 5 hours of sleep has been shown to increase performance for up to two hours (van den Heuvel et al., 2003).

The International Labour Office states that ATCs should work no more than two consecutive night shifts. There is some evidence that says four recovery days are needed after a worker works seven consecutive night shifts, however, research in this area is required for scientifically based guidelines to be developed (van den Heuvel et al., 2003).

Personal and At-Work Countermeasures. Potential fatigue countermeasures for controllers were discussed in a literature review on fatigue in controllers in 2000 and in a 2007 pamphlet published by EUROCONTROL (Marcil and Vincent 2000; EUROCONTROL, 2007). The 2000 literature review discussed several potential strategies for maintaining and improving alertness. Control facilities in the U.S. typically have low light levels, however, increasing lighting levels was suggested as a potential countermeasure, as bright lights can postpone sleep and improve vigilance. Melatonin was also included in the discussion of potential countermeasures. The review noted that due to the shift schedules that controllers work and the potential residual effects of melatonin, more research to determine the benefits of melatonin and specific dosing times would have to be identified before it can be recommended for use by controllers (Marcil and Vincent, 2000). Coffee was also a suggested short-term countermeasure. To prevent lowered alertness that can be induced from boredom on the night shift and during other low level traffic times, keeping the controllers busy with simulations was suggested as a possible solution, as was exercise and conversing with colleagues. Educational training for controllers including information on sleep strategies was also suggested (Marcil and Vincent, 2000).

In the EUROCONTROL pamphlet includes tips on bedtime rituals, light exposure, alcohol, nicotine, caffeine, music, noise, diet, exercise, medicine, and relaxation techniques. Regarding alertness at work, like the literature review, exercise and conversing with colleagues during breaks is suggested. Additionally, eating three meals a day and drinking caffeine early in the shift are also suggested (EUROCONTROL, 2007).

Both the 2000 literature review and the EUROCONTROL pamphlet include napping during breaks for helping preserve performance, reduce fatigue and improve alertness, particularly on the night shift (Marcil and Vincent, 2000; EUROCONTROL, 2007).

Napping. Napping as a countermeasure for controllers on the night shift has been investigated in the U.S. in a simulation study and in New Zealand in a radar facility. The study in the U.S. was a 4 day laboratory simulation that involved 59 military and civilian ATCs. Physiological, performance, and subjective data were collected to assess if naps affected sleepiness and performance. The results "…suggest[ed] that naps taken during the midnight shift could be useful as a countermeasure to performance decrement and sleepiness on the midnight shift" (Della Rocco, Comperatore, Caldwell, Cruz, 2000, pg. i). The New Zealand study was a field study conducted over eight months. Physiological, performance, and subjective data were collected from 28 upper level airspace radar controllers working early (22:30-06:00) and late (23:30-06:30) night shifts to evaluate the effect of a 40 minute nap opportunity on performance and alertness on the night shift. As part of this evaluation, the ability of the controllers to nap during the opportunity and the association between sleep structure and subsequent performance and alertness was also assessed. The average amount of sleep obtained during the nap opportunity was 19 minutes on the early night shift and 20 minutes on the late night shift. The nap opportunity was observed to reduce spectral power and likelihood of slow rolling eye movements during the last hour of the controllers shift. The nap opportunity improved performance of the controllers, but it was still not enough to preserve performance for the entire night shift as degradation still occurred (Signal, Gander, Anderson, Brash, 2009).

2.2.2.3 Fatigue Risk Management Systems in ATC

Formal approaches to mitigating fatigue have focused on the concept of Fatigue Risk Management Systems (FRMSs). FRMSs are in use across various industries, including, aviation, ATC, rail, nuclear power plants, mining, trucking, and emergency services, among others. FRMSs rely on continuous measurements of fatigue risk factors to gauge the likelihood of fatigue and an active culture to derive strategies to decrease either the likelihood of fatigue or reduce the impact of its occurrence. FRMSs in place in ATC settings are described here. Organizations from comparable industries that currently have FRMSs implemented or are investigating FRMSs are discussed in Appendix E.

2.2.2.3.1 New Zealand

In 1999, New Zealand issued a Notice of Proposed Rulemaking (NPRM) that would allow ATC providers to use a fatigue management system in place of hours of service (HOS) rules, after the FRMS had been approved by the Civil Aviation Authority's director. The FRMS had to take into account seven factors: time off before a shift, workload, break patterns, staff levels, circadian rhythms, short-term sleep loss, accumulated sleep loss, and the rotation pattern used. Also, the FRMS needed to include workload monitoring, acknowledgement of fatigue's role in accidents and incidents, staff education on fatigue and fatigue avoidance, a managerial responsibility for avoiding fatigue, and limits pertaining to: max time of continuous duty, min break time, max time of duty day, min time off between consecutive workdays, min time off after a night shift, max consecutive duty days, max consecutive night shifts, max average duty during a shift cycle, and either the min days off in a four-week period (if the shift cycle was based on a calendar week) or the min days off in a multiple of the shift cycle that would be closest to 28 days (if shift cycle was not based on a calendar week). Additionally, the FRMS had to include information on how the previously defined items would be modifiable during situations that involved an emergency, the safety of a person's life or property, or off-nominal operations, as well as develop procedures to ensure all ATCs worked schedules according to the scheme illustrated in the FRMS and developed procedures to ensure fatigued individuals that would endanger safety were identified and not permitted to work (Civil Aviation Authority [CAA] of New Zealand, 1999).

Even though the NPRM and an associated draft Advisory Circular were developed to address the ATC fatigue management issue, the NPRM was never was approved or put into effect (Perris, 2008) and Civil Aviation Rule (CAR) Part 172, Air Traffic Service Organisations—Certification, does not include a FRMS, although there is a place for it, 172.55 Prevention of fatigue [Reserved] (CAR 172, 2010). At the Fatigue Management Implementation Project workshop in 2006, ATC and maintenance personnel were identified as lacking and needing FRMSs. Most recently, at the Fatigue Risk Management IAG's meeting on May 24, 2010, it was reiterated that ATC and maintenance personnel need FRMSs (Fatigue Risk Management Issue Assessment Group, 2010).

2.2.3 Models to Predict Controller Fatigue

The ultimate goal in understanding fatigue is to be able to project its presence in advance of manifestation. This enables air traffic managers to proactively mitigate risk through multiple means, including schedule adjustment or special accommodation if the schedule cannot be affected. Overall, this is an area largely unserved by previous research.

Appendix D summarizes the research found related to the modeling of fatigue. Existing models to measure and analyze fatigue risk as well as an evaluation of modeling techniques from both civilian and military applications were considered. Given that it is already planned for use by FAA, the Fatigue Avoidance Scheduling Tool (FAST) model was not reviewed. Other than limited research found from Australia and within the U.S. airline community, very little has been done in this area.

Studies of controller performance under different levels of automation, technology, work hours, and task environments are typically performed within air traffic management (ATM) experiments in airspace simulation environments, such as AirMIDAS (Corker et al, 2000). An integral part of these simulations is therefore a model of controller mental image, workload, and/or performance. Such controller models attempt to consider detailed approximations of controller cognitive processes (and task decompositions), psychological findings and theories, response timing, and position (tower vs. en-route). Model outputs generally predict variables such as workload, conflict detection and response time, and performance levels (accuracy). The models may be rule-based systems, mathematical expressions, or agent-based models. Despite the importance of the controller model in the airspace simulation, and the importance of fatigue in human controller performance, there appears to be no explicit discussion of fatigue in the current models.

A thorough review of air traffic controller modeling for traffic simulations appears in De Prins, Ledesma, Mulder, and van Paassen (2008). A taxonomy of models is presented and the contributions of several specific models are discussed. This work does not attempt to link controller performance modeling to controller fatigue. That remains a key gap, but some of the fundamental analysis on operational performance modeling has been done and would provide a solid base to build from.

3 Identification of Gaps and Recommendations

This section identifies the gaps in the knowledge of fatigue and ATCs. Recommendations for filling the gaps are included.

3.1 Filling Gaps in Knowledge

Identified gaps were prioritized based on the estimated risk to safety in the NAS from highest to lowest. Next studies were outlined to fill those gaps. The studies recommended in this section evaluate measures of air traffic controller fatigue, identify potential fatigue risks and their countermeasures, and expand existing models to predict air traffic controller fatigue as an effect of workload and controller proficiency. A major contribution of this document is to help highlight the areas of research that are currently lacking and to encourage a collaborative effort to achieve a broader understanding of the causal factors for fatigue in aviation as well as investigate how these factors interact. Undoubtedly over time additional studies will be identified especially as the Article 55 recommended scheduling practices and FRMS metrics are reviewed and problems identified.

3.2 Priority 1 Quantify Air Traffic Controller Fatigue

Field fatigue measurements have not been performed on all ATC positions. The majority of the literature reviewed did not always clearly identify the positions that were tested. Positions were identified as Center controllers, En Route, TRACON, Radar Approach, terminal, tower, or military. Positions not identified in the research are the following:

- Within the Center positions that were not identified in the research were:
  - Supervisory Traffic Management Coordinator (STMC).
  - Traffic Management Coordinators—Coordinator Planner, Monitor Alert Coordinator, Arrival and Departure Sequencing Coordinator, En Route Spacing Coordinators, and Floor Walker.
- Within the TRACON positions that were not identified in the research were:
  - Coordinator.
  - Assistant/D-Side Controller.
- Within the Ground/Tower positions that were not identified in the research were:
  - Clearance Delivery.

To fill this gap, measure fatigue on ATC positions for which there are no measurements in the published literature, unpublished work at CAMI, or the current NASA survey and study. Further fatigue of the controllers at the above positions should be measured using standard metrics such as those listed in Appendix G.

3.3 Priority 2 Validate Measures of Air Traffic Controller Performance Sensitive to Fatigue

The literature search did not identify any validated measures of the effects of fatigue on air traffic controller performance. This is especially true in relation to individual differences among controllers. Such measures are critical for monitoring the effectiveness of fatigue countermeasures (see Appendix E) put in place as part of a FRMS.

- Critical support for FRMSs monitoring:
  - Validation of air traffic controller measures of performance sensitive to the effects of fatigue and able to discriminate the effectiveness of fatigue countermeasures.
  - Evaluation of joint effects of multiple factors in addition to fatigue.
  - Longitudinal studies on individuals over years to identify the long-term effects of cumulative fatigue.
  - Data to support tailoring FRMSs to specific populations including ATCs with varying levels of proficiency.

To fill this gap it is necessary to develop and validate methods to monitor the effectiveness of fatigue countermeasures introduced into ATC facilities, to identify methods of measuring air traffic controller cognitive and physical performance, to identify the costs and benefit of each as well as the appropriate time and place to use each measurement method, and whether the measurement methods work effectively in both the laboratory and the operational setting.

Study One - Investigate the availability of tools that can estimate the time history of workload and complexity of sectors during the day from recorded data. Determine the feasibility of computing the cumulative workload and complexity exposure of an individual controller during his or her shift, by summing the measures that account for his or her duties (R-controller, D-controller, Tracker, etc.) during the periods that he or she was on position. Such metrics would permit the assessment of work-induced fatigue on the probability of OEs. These metrics might also show the degree to which cumulative workload and complexity exposure contribute to fatigue as measured by fatigue estimates from empirical voice or data measurements. The availability of tools that estimate the time history of workload and complexity of sectors provide the opportunity to acquire substantial amounts of data over extended periods and for a large number of subjects. Such large amounts of data are critical to meaningful assessments of fatigue that presumably occur infrequently for individual controllers.

Study Two - Investigate the level of text recognition software and explore the feasibility of tailoring such software to recognize reduced controller performance that may stem from fatigue. Such tailored software would not strive to create a full transcript of the controller's speech, but would count the occurrences of phrases such as "Correction", "Negative", "Say Again", and “Standby" in the controller's voice track. A version of such software could be operated unobtrusively in situ or on substantial quantities of recorded voice data. Processing of such data for an individual controller over an extended period could produce a norm for that controller. Excursions from that norm might be used to indicate periods where performance is degraded from fatigue. It is understood that increased counts of these phrases might be caused by both increased workload/complexity and periods of fatigue from work duties or other sources. Correlation of fatigue metrics with workload/complexity metrics as described in the preceding paragraph would enable the identification periods when the increased incidence of fatigue-related phrases cannot be accounted for by increased workload/complexity and therefore may be attributed to fatigue.

Study Three - A study is needed to evaluate current FRMSs to determine their effectiveness and identify which portions of the system are most supportive. To do this it is important to first identify the metrics that will make this determination. These may include multiple performance metrics, scheduling practices, reduction in operator ratings of fatigue, increased safety, and the overall economic impact. Cognitive performance has been suggested as an indicator of fatigue (Angus and Heslegrave, 1985; Ansiau, Wild, Niezborala, Rouch, and Marquié, 2008; Deary and Tait, 1987; Gunzelmann and Gluck, 2008; Ikegami et al., 2009; Jacques, Lynch, and Samkoff, 1990; McLellan, Kamimori, Voss, Tate, and Smith, 2007; Orton and Gruzelier, 1989; Pilcher and Walters, 1997; Rowe, French, Neville, and Eddy, 1992; Van Dongen et al., 2007; Vrijkotte, Valk, Vennstra, and Visser, 2004). For this reason, it is important to determine the most effective measures for cognitive performance for implementation with FRMSs.

Study Four - Test a method of eye tracking and change blindness to determine an individual's level of fatigue. Change blindness occurs often during monotonous tasks wherein the individual misses or does not observe changes that occur (Wickens, Hooey, Gore, Sebok, and Koenicke, 2009). Change blindness may occur as a result of inattention or perceptual failures. This research will contribute to research on monotony, vigilance, and measurement techniques for fatigue.

Study Five - The auditory working-memory vigilance task (AWVT) (Athènes et al., 2002; Tyagi, Shen, Shao, and Li, 2008) is a new measurement method which attempts to objectively measure mental fatigue with respect to the user's current cognitive abilities. Through measuring the user's working-memory, decision-making ability, and vigilance, information may be gained concerning the individual's higher mental abilities at any given time. The scores derived from this test, the AWVT Fatigue Index (AFI), are suggested to reflect mental fatigue level. This measurement method requires further study and validation and will contribute to the toolkit of possible fatigue measurement methods.

3.4 Priority 3 Validate Individualizing Shift Schedules

While there are many studies on shiftwork, oftentimes the results are incomplete or contradictory to past research. Further research needs to be performed to evaluate the effects of shiftwork on certain demographics, personalities, and its long term effects on ATCSs. Actigraphy data were used in many of the studies to evaluate an individual's sleep habits and sleep quality. Could actigraphy data be used as a method of monitoring an individual to determine whether they are fit to work? Shiftwork has been implicated as a contributing factor to fatigue, errors occurring during all levels of workload, communication problems, and lapses in situational awareness (SA). Evaluation is needed to determine the countermeasures that will actually assist in alleviating and preventing these issues. There are many recommendations on preventing fatigue, however, the majority of these recommendations are based on theoretical ideas and have a limited source of research to back up the claims (Marcil and Vincent, 2000; Galliard, 2003). Research is needed to address the following questions related to shiftwork for ATCs:

- Personality— what personality types perform better/worse on shiftwork?
- Demographics— are there age differences between those who perform better/worse?
- Cognitive performance— when are the peaks/valleys in cognitive performance during shiftwork? How can cognitive performance be increased/sustained?
- Communicative vigilance— what factors are causing a decrease in communication and how can better vigilance be obtained?
- SA— does shiftwork contribute to lapses in SA? Do lapses occur more frequently when individuals are fatigued?
- Longitudinal effects— what are the long-term effects of shiftwork for ATCs?

A study to determine which measures are needed to cater individualized scheduling[4] to support ATCs in developing work schedules to suit their circadian rhythms is recommended. This may also help to inform ATCs on the best time for breaks and further fatigue risk factors. This research will contribute to past research in scheduling and circadian rhythms.

As a secondary study, determine when individuals are at their highest and lowest cognitive peaks. This can be done through an analysis of scheduling, Psychomotor Vigilance Test (PVT), overall performance, and evaluation of the individuals Fatigue Audit InterDyne (FAID) and sleep/wake model. From this, Traffic Management Coordinators (TMCs) will be aware of the times of day when individuals may be suffering from fatigue conditions. This may also provide insight regarding the best times for breaks and/or naps. This research will contribute to the literature by filling the gap in task duration/time-on-task, breaks and napping, and vigilance.

3.5 Priority 4 Collect Data to Support Sleep Disorder Policy

The prevalence of sleep disorders in the general population (see Appendix I) indicates a need to answer the following questions:

- Should sleep apnea (and other sleep disorders) screening be an employment condition?
- How will the screening be done cost effectively?
- What are the most effective protocols for screening aviation professionals?

Following suit of the Israeli commercial driving industry, a question regarding Body Mass Index (BMI) could be added to the aviation medical exam form and those that have a BMI ≥ 32 and thus are at greater risk for OSA could be referred for further testing. Another option would be to

[4] Fatigue encompasses many different concepts and physical and mental states, it is important to evaluate fatigue with regard to all the situations that may cause an individual to become fatigued. An individual’s personality could help identify who is more susceptible to fatigue, lapses due to workload or poor situation awareness, and their susceptibility towards monotony and fatigue. Further research should be performed to identify inherent risk factors for fatigue.

follow the example of the rail industry and instead of including a BMI question, include the Epworth Sleepiness Scale (ESS) into the medical exam to identify those at risk for Excessive Daytime Sleepiness (EDS). As cost is a concern for a standard that might come from research on the topic, rather than performing a Multiple Sleep Latency Test (MSLT) and PSG, the controller could undergo an at-home study using a single channel monitor (the ApneaLink™ or Flow Wizard, for example). Studies found these two monitors to be potential tools for ruling OSA in or out for research studies or for ruling OSA as in or out for patients with a high probability for OSA. Results should be confirmed with MSLTs and PSGs to see if the single channel monitors or the ESS would be a useful and lower cost tool for identifying controllers with previously undetected OSA/EDS. Comparison of PSG and single channel monitors with other home monitors that record more than one channel such as the SNAP or ApnoeScreen could also be completed to see if the agreement between the two (in terms of diagnosis) is better than a single channel monitor. A cost-benefit analysis should be done as well as a comparison of the sensitivities in determining the best choice. This research will contribute to the literature on sleep and sleep related breathing disorders (SRBDs).

3.6 Priority 5 Validate Human Performance Models To Predict ATC Fatigue

Field tests of air traffic controller fatigue are costly, time consuming, and may only reflect a portion of the entire population of 20,000 ATCSs. To efficiently predict the effects of fatigue countermeasures, human performance models should be enhanced to reflect individual differences and validated. These should be applied and evaluated in ATC. Specifically, build and validate a controller functionality model to assess the functionality, on an individual level, of a controller. Such a model should integrate the best components from human fatigue models and controller models. There will likely be a mathematical component describing the 2-process model of fatigue, as well as a Flight Operations Risk Assessment System (FORAS) hierarchical rule-based model which can integrate other contributing factors less easily mathematically modeled using the standard approaches. This model should provide an assessment per-person, per-duty. In particular, to provide a per-person analysis, the model inputs will depend on individualized inputs, rather than generic population averages, wherever possible. The model will also include components relating to long-term (approximately one year) fatigue—a factor missing from most human fatigue models. Additional research into fatigue at this scale may be required to support this.

Variables could include sleep schedules, circadian rhythms and changes due to time zones, self-assessed fatigue, linguistics data, controller position, time on task, workload experienced including durations, and a record of any errors that occur. A number of measurements including PVT scores can be calculated at different time intervals to quantify concepts such as cognitive performance and vigilance. Regression modeling techniques would help identify which factors are strongly correlated with the cognitive performance measurements and would also yield a characterization of fatigue using all of the significant causal factors. A model can then be constructed to capture the effects of fatigue over extended periods of time. Individualized models could be studied to estimate a fatigue score for each controller based on their physiological needs as well as their skill sets. This research would contribute to the literature on sleep and circadian rhythms, measurement techniques, human performance modeling, and cognitive performance.

In a second study, demonstrate, understand, and model the connection between fatigue assessment, alertness, and human performance in the controller setting. Finally, validate the model, using the measurements and methodologies described in previous sections, to relate fatigue factors to real controller performance.

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Appendix A Aircrew

Studies of aircrew fatigue have been performed on both civilian and military aircrews across a wide range of missions.

A.1 Civilian Aircrews

Many fatigue studies are performed in simulators. Most use measures of aircraft related task performance as the dependent variable. Some add laboratory type tasks, for example the PVT, to the aircrew's duties.

Roach, Petrilli, Dawson, and Thomas (2006) measured the performance of 134 pilots who were divided into 67 crew comprised of one Captain and one First Officer after at least four days of consecutive days of free duty (rested) or immediately after final landing at the end of an international flight (not rested). The crews flew 70 minutes in a B747-400 simulator during which they had to respond to a locked out engine, load sheet error, runway change, level off altitude change, request to expedite climb, request to maximize speed, respond to erroneous pressure setting, and no clearance to land. The data were threat and error management. There was no significant effect of fatigue on threat detection. However, for threat management there were significantly more errors (40.3%) if the Captain and First Officer had less than 5 hours of sleep in the last twenty four hours than if they had more than 5 hours (26.0%). A similar result occurred for error management. If the Captain and First Officer had less than 4 hours of sleep in the last twenty four they made significantly more errors (11.7 per flight sector) than if they had more than 4 hours (8.4 errors per flight sector). Rested crews detected 44.3% of their errors while nonrested detected 56.9% of their errors. Finally, if the Captain and First Officer had more than six hours of sleep in the previous twenty four, they detected 44.3% of their errors. In contrast those with less than 6 hours detected 56.2% of their errors.

Neri et al. (2002) compared the PVT performance of 14 pilot/copilot crews after 18 to 20 hours without sleep. The crews flew an uneventful six hour flight in a Boeing 747-400 flight simulator. Seven crews took a 15 minute break halfway through the flight. The other seven did not. The captain completed the PVT minutes 22 through 32 each hour of the six hour flight; the copilot minutes 32 through 42 of each hour of the flight. There was no significant difference in PVT performance prior to the simulated flight. There was a significant effect of time but not of break. The worst performance occurred between 5:50 and 6:50 am.

In a field study with flight attendants, Beh and McLaughlin (1991) measured the performance of 46 flight attendants on a series of tasks: logical reasoning, vertical addition, horizontal addition, letter cancellation, and Stroop card sorting. Data were collected one hour prior to departure and during each layover on a series of three or five flights. A control group of flight attendants who were not flying took the tests at the same time as the flight attendants who were flying. For grammatical reasoning there was a significant decrease in the performance of flying attendants than the control group at all post-flight test periods. The flying group did significantly worse during layovers than during the pre-test. The same result was observed for the vertical addition task and one card sorting task. Letter cancellation performance was only significantly different between the two groups on the last layover.

Subsequent to three fatal, commercial aviation accidents (ATI in 1995, Corporate Airline in 2004, and Colgan Airlines in 2009 in which fatigue may have been a contributing factor) and a previous failed attempt to change existing flight, duty and rest regulations, in June 2009, the FAA chartered the Flight and Duty Time Limitations and Rest Requirements ARC to develop recommendations for an FAA rule based on current fatigue science and a thorough review of international approaches to the issue.

According the FAA's just-published Flightcrew member Duty and Rest Requirements Notice of Proposed Rulemaking (FAA, 2010), the FAA asked the ARC to specifically consider and address the following:

- "A single approach to addressing fatigue that consolidates and replaces existing regulatory requirements for parts 121 and 135.
- Generally accepted principals of human physiology, performance and alertness based on the body of fatigue science.
- Information on sources of aviation fatigue.
- Current approaches to address fatigue strategies in international standards.
- The incorporation of fatigue risk management systems (FRMS) into a rulemaking."[5]

The ARC, comprised of representatives of labor, industry and FAA, met over a period of six weeks during the summer of 2010 and on September 9, 2010, the ARC delivered its final report to the FAA in the form of a draft NPRM. The NPRM was published in the *Federal Register* on September 14, 2010 and the FAA has invited interested persons to participate in the rulemaking by submitting written comments, data, or views.

Briefly, current FAA duty and rest requirements limit duty time to sixteen hours with eight hours of rest required between work periods. The NPRM proposes the application of a sliding scale starting at nine hours and maxing out at a thirteen hour duty day, depending on the time of day when the duty day began and the number of flight segments included in the duty day. Current rules limit flight time (the time during which the aircraft is actually in motion) to eight hours; the NPRM proposes an increase to eight to ten hours, depending on the type of flight and the number of flight segments. The NPRM also proposes a minimum of thirty consecutive, duty-free hours during any seven-day period and would establish duty hour limits for twenty-eight day and annual periods.

Finally, the NPRM proposes a minimum of nine hours of crew rest between duty periods, with the rest period commencing when the crewmember arrives home or at his/her hotel, as opposed to the current rule which establishes an eight-hour minimum rest period that commences when the aircraft arrives at the gate.

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[5] Federal Register, Sept 14, 2010, Notice of Proposed Rulemaking (NPRM) 14 CFR Parts 117 and 121, Docket No. FAA-2009-1093; Notice No. 10-11, Flightcrew Member Duty and Rest Requirements

A.2 Military Aircrews

Russo et al. (2005) evaluated the performance of eight Air Force pilots during a simulated 12.5 hour air refueling mission. The data were collected in a flight simulator and included choice reaction, deviation from azimuth heading, and for the PVT: speed, lapse, false start, and anticipation. There were significant impairments at 19 hours awake: choice reaction time omissions, azimuth deviations, PVT speed and lapses.

In another flight simulator study, Van Dongen, Caldwell, and Caldwell (2006) examined the performance of 10 F-117 pilots over 5 sessions in an F-117A high fidelity flight simulator culminating in 38 hours of sustained wakefulness. The pilots' performance in the flight simulator as well as on a fitness for duty test was analyzed. There were significant differences in performance degradation as a function of time: heading during straight and level flight, roll during right 360º turn at an altitude of 11,000 ft. mean sea level (MSL), roll and indicated airspeed during left 360º turn at an altitude of 11,000 ft. MSL, altitude, indicated airspeed and roll during left 720º turn at an altitude of 15,000 ft. MSL, indicated airspeed during a climb, indicated airspeed and indicated vertical speed descending right 360º turn to an altitude of 10,000 ft. MSL, and indicated airspeed, indicated vertical speed, and roll during climbing left 540º turn to an altitude of 15,000 ft. MSL. The authors concluded that there are individual differences in responses to sleep losses even in highly select populations such as F-117 pilots.

A similar study with Unmanned Aerial Vehicles (UAVs), Thompson, Lopez, Hickey, DaLuz, and Caldwell (2006) conducted a field study of 28 pilots, sensor operators, and intelligence personnel performing USAF MQ-1 Predator missions in Afghanistan and Iraq from Nellis Air Force Base, Nevada. All participants were permanently assigned, full time, and had been performing shift work for at least three months. Fatigue was measured using the composite fatigue scale. An Actiwatch® was used to identify activity and rest periods as well as a standardized sleep/activity log. Piloting performance was assessed using the unmanned aerial vehicle synthetic task environment (UAV STE), a Predator simulator. Cognitive performance was assessed from a self-paced mental arithmetic task; vigilance from the PVT; boredom from the boredom proneness scale; mood from the Profile of Mood States. Data were collected post-shift on days 1 through 4 and both pre- and post-shift on days 5 and 6. The authors concluded that over half of the operators reported symptoms associated with Shift Work Sleep Disorder. The participants also had decrements in cognitive and piloting performance as well as alertness. Specifically throughput on the math test decreased 5.1% between pre- and post-shift. There was also a 5.1% increase in reaction time to the PVT from pre- to post-shift. Also root mean square (RMS) error deviation increased from pre- to post-shift in altitude (-15.75%), heading (-5.32%), and airspeed (184.56%). Higher boredom periods were associated with slower response times. Finally mood disturbance scores increased from pre- to post-shift for those who worked nights but not days or evenings and for those on rapid rotation schedules rather than slow rotation schedules.

Thompson and Tvaryanas (2006) (and Tvaryanas and Thompson, 2006) reported the results of a fatigue survey of 172 United States Air Force personnel who have shiftwork schedules. The survey was undertaken after 12 percent of shiftworkers involved in ground mishaps and OEs identified fatigue as a factor. The groups included in the survey: 1) unmanned aircraft system

(UAS) crewmembers, 2) UAS maintenance personnel, 3) manned aircraft (MA) crewmembers, and 4) MA maintenance personnel. The authors concluded that self-reported average daily sleep and sleep quality did not correlate with fatigue, groups 1 and 2 reported greater fatigue than groups 3 and 4, crew and maintenance personnel reported equal levels of fatigue, and shift workers were equally fatigued at home base as deployed. Fatigue was measured using a composite fatigue survey derived from the fatigue scale (FS), checklist individual strength concentration subscale (CISCON), fatigue assessment scale (FAS), World Health Organization quality of life assessment energy and fatigue subscale (EF-WHOQOL), and Maslach burnout inventory emotional exhaustion subscale (MBI-EE). A second survey of UAS crews was conducted after the shift work schedule was modified. There was no significant reduction in fatigue (Tvaryanas, Platte, Swigart, Coleback, and Miller, 2008).

Appendix B Comparable Environments

Fatigue can arise from two sources: sleep loss and time on duty. The causes of sleep loss include injury associated with physical fatigue, psychological stress, mental illness, disease, sleep disorders, desynchronosis with circadian and other biological rhythms, and sustained operations. Each of these has different effects on performance since each of these affects how quickly a person can recover the sleep debt, the quality of that sleep, and the duration of exposure to that cause of sleep loss. For injury and disease, performance decrements may be due to sleep loss but more likely to the injury or the disease itself. An example of comorbid conditions, depression, and sleep quality is presented by Hayashino, Yamazaki, Takegami, Nakayama, Sokejima, and Fukuhara (2010). The focus of this section is on the effect of sleep loss *not known to be* associated with injury, illness, disease, or desynchronosis on operators in environments comparable to ATC. These environments include military command and control, security surveillance, process control, and medical environments. In addition, studies of operator safety during the drive home from work are also reviewed.

B.1 Security Surveillance

In security, both loss of sleep and work at night degrades operator performance. Basner et al. (2008) recorded the accuracy of detecting threats in a simulated luggage screening task over a five day period. There were twenty-four subjects who were tasked at night and also after a night without sleep. At night there was a significant decrease in accuracy of detection and a significant increase in false alarm rate compared with performance during the day. Performance after a night without sleep showed significant further decreases in accuracy and hit rate.

B.2 Military Command and Control

Military command and control research has been conducted using both ground and airborne operators.

Ground-based Command and Control. Neri, Dinges, and Rosekind (1997) summarized the literature relevant to military surge operations with similar decrements in visual performance as a function of sleep loss. However, DeJohn, Reams, and Hochhaus (1992) compared performance on cognitive, visual, and auditory tasks before and after an extended overwater training mission. There were no significant differences in the performance of the cognitive or visual tasks. There was an improvement in understanding of noise degraded speech. The authors concluded that the improvement was due to practice. Tyagi et al. (2009) compared the performance of eight male students on an auditory working-memory vigilance task as well as PVT over the course of a 25 hour sleep deprivation study. Data were collected hourly. There was a significant effect of sleep deprivation in comparing across time.

Baranski et al. (2007) measured the performance of 64 adults composed of 4 person teams. Eight teams consisted of military person, the other eight of civilians. Participants made individual or team decisions while playing the Team and Individual Threat Assessment Task (TITAN), a computer simulation of a naval shipboard surveillance and threat assessment task. During day 1 participants were trained, fed (no caffeine after noon), and allowed to sleep. Civilians spent significantly more time in bed than the military participants but also spent significantly more time in bed being awake. Assessment errors decreased and target processing time decreased from day 2 0800 through day 2 1900. Both steadily increased from that point until the end of the experiment (day 3 1000). Further military teams had significantly longer target processing times than the civilians. There was not significant effect of subordinate feedback on either error or time. But teams had significantly better performance than individual’s solo performance as the amount of sleep deprivation increased. After 30 hours there was a 2% difference in percent errors and 14 second difference in target processing time.

Lieberman et al. (2006) evaluated the performance of thirteen male soldiers over a four day sustained operations mission. Tasks included set up and pack a command post, land navigation, battle drills, road march, obstacle course, litter carry, unload truck, 50 minute walk at 3.5 mph 7% grade in 35 degree Centigrade temperature, physical training, and light training. In addition cognitive and physical performance tests were given. Visual vigilance significantly decreased in days 3 and 4 of the sustained operations mission but only in the number of hits not in the number of false alarms or in the reaction time. However, there were significant decreases in the number of correct responses on a four-choice reaction time task on day three of the sustained operations mission as well as an increase in reaction time.

McLellan et al. (2007) examined the performance of twenty male New Zealand Special Operations personnel. These personnel were given with caffeine or a placebo over a five day period. During this time they completed an obstacle course and performed a vigilance task which required them to record where, when, and what activity occurred in a building under observation. The vigilance task lasted 120 minutes and was scored with one point for every correct answer. The group using the caffeine gum had significantly higher vigilance scores on days three through five than the placebo group. The caffeine group also did significantly better during three overnight testing periods. Night vigilance was significantly less for both groups on day four as compared to day three.

In a larger study, Castellani, Nindl, Lieberman, and Montain (2006) compared performance of 13 male soldiers over two 84 hour periods: control and sustained operations. The sustained operations included 49 hours of military tasks. Cognitive and physical performance was measured the morning of days 1, 3, and 4 of each 84 hour period. The cognitive tests were visual vigilance, four-choice reaction time, matching to sample, and repeat of a 12 key press pattern. The number of correct detections in the visual vigilance task decreased over the experiment in both conditions. For the four Choice Reaction Time test the number of correct responses decreased over time and the number of errors increased. The total number of errors was highest on day 4 of the sustained operations condition. For the matching to sample, the number of timeout errors increased across the experiment.

Airborne Command and Control. Both the United States Air Force and Navy have airborne command and controller. For the Air Force, it is Airborne Warning and Control System (AWACS) operators. There are up to 14 mission crew in the cabin of the E-3 aircraft. For the Navy, the E-2 carries three mission personnel: combat information center officer, the air control officer, and the radar operator. Fatigue of these aircrews was a concern among both services. The

Air Force designed a research specifically to study sustained operations in the AWACS (Shiflett, Strome, Eddy, and Dalrymple, 1990). Chaiken et al. (2004) evaluated the performance of ten three-person crews drawn from United States air Force officers awaiting Air Battle Management training. Each participant completed nine hours of training on the Automated Neuropsychological Assessment Metric (ANAM) cognitive task battery and 30 hours of training on an AWACS simulation and decision support system. They performed command and control tasks from 1830 to 1100 the following morning. The tasks included control of surveillance aerial vehicles, airstrike coordinated between bombers and airborne jammers, and controlling air-to-air fighters. ANAM scores indicated an initial increase in performance following by decrease to the early morning hours and a recovery mid-morning. Mission dependent variables were no gas (i.e., (poor fuel management), threat killed, and friendlies lost. There was a small but significant increase in the hostile penetrations with fatigue and a concordant decrease in the number of threats killed. In addition there was a significant increase in "return to base" order with fatigue, especially with the air-to-ground mission. Finally fewer tactical orders were given during the later hours of the day.

Using a similar simulation, Whitmore, Chaiken, Fischer, Harrison, and Harville (2008) measured the performance of 30 United States officers over a 30 hour period performing airborne command and control tasks as well as ANAM tasks. There was only one significant effect on individual performance—the number of friendly aircraft attacked did not return to the baseline level during the recovery day. However, the number of air target engaged during the recovery period was significantly higher than during the baseline trial. For the teams, there were significantly more air targets engaged during recovery than during baseline. There were also significant decrements in performance over time in the ANAM continuous processing and math tasks. For math there was a recovery above baseline at the end of the experiment.

B.3 Process Control

Most process control studies require participants to perform laboratory tasks before, during, or after a shift. For example, Mitchell and Williamson (2000) compared the performance of 15 employees working 8-hour shifts in an electric power plant versus that of 12 employees working 12-hour shifts. Tasks were a five minute simple reaction time task, a three minute grammatical reasoning task, a ten minute vigilance task, and a five minute critical tracking task. Employees had significantly faster reaction time at the end than at the beginning of the shift on the simple reaction time task. Employees on the 12-hour shift also had more variance in the reaction time for correct responses to the grammatical reasoning task. For these employees there were significantly more errors in the vigilance task at the end of the shift as well.

In a larger study, Ansiau et al. (2008) compared cognitive performances of 2,337 workers during a yearly medical exam. The cognitive tasks were immediate free recall from a list of 16 words, delayed free recall, digit symbol substitution, and selective attention. Ages were 32, 42, 52, and 62. Both males (1,152) and females (1,185) were included in the analysis. Most reported typical work schedule (1,911), less than 8 hours working (1,511), low workload (1,911), and mental tasks (956) rather than physical (679) or social (702). About half woke at least once during the previous night (1,182). Some had difficulty getting back to sleep (424). The group was split on sleep dissatisfaction (yes 1,169, no 1,168). A decrease in sleep length was significantly associated with being 52 (rather than 32), having worked more than 10 hours the previous day (rather than less than 8 hours), with atypical schedule and having a high workload. The number of awakenings was greater for 52 or 62 year olds, working between 8 and 10 hours on the previous day, and reporting higher workload. Higher age was negatively associated with performance of all cognitive tests. Working prior to 6 a.m. or after 10 p.m. on the previous day was associated with poorer performance on three of the tasks (immediate and delayed recall, selective attention). Bedtime was not significantly associated with performance on any of the four cognitive tasks. Persons working mental tasks on the previous day had significantly better performance on the cognitive tasks than those who reported working on physical tasks on the previous day. Performing social tasks on the previous day was associated with better performance on immediate and delayed recall and digit symbol substitution. Unexpectedly, higher sleep lengths were associated with poorer performance on the selective attention ask.

In a field study of twenty male smelter workers over a 14 day period, Baulk, Fletcher, Kandelaars, Dawson, and Roach (2009) measured (using a diary as well as activity monitors) sleep, subjective fatigue, and performance on the PVT completed at the beginning, middle, and end of each shift. Less sleep was obtained on the second night of shift work than on the first night. Subjective fatigue was higher after a shift than before it. The PVT response was slower for the night shift and degraded from the first to the second night of shift work.

Using a different research paradigm, Barnes and Wagner (2009) analyzed the injury rates for miners from 1983 to 2006 based on data reported to the Mine Safety and Health Administration. There was a significant increase with an hour lost due to converting to Daylight Savings Time but no significant change with an hour gained due to the return to Standard Time. In a second study, the authors used the American Time Use Survey data for 2004 through 2006. These data are collected through telephone interviews made by employees of the Bureau of Labor Statistics. On average people slept 40 minutes less after converting to Daylight Savings Time than on days without the shift. Further the loss of sleep was greater than the gain of sleep with the return to Standard Time. The authors suggest that the increase in injury rate may be associated with the sleep loss.

B.4 Medicine

Many studies compare performance on laboratory tasks across duty days as well as between participants who are rested and those who are not. A few studies examined the effect of fatigue on actual medical tasks. Studies have focused on interns but some have also included nurses.

Same Participants Across Duty Days. Some studies are across a single day. In an early study using grammatical reasoning, Poulton, Hunt, Carpenter, and Edwards (1978) reported a significant reduction in efficiency (i.e., number completed per three minute trial) on this test with a sleep deficit of 3 hours or more. The participants were 30 junior hospital doctors. Sleep debt was calculated from duty and sleep charts.

Orton and Gruzelier (1989) measured the performance of 20 house officers in a British hospital twice—once mid-afternoon near the end of a day shift and once near the end of a day shift that had followed a night shift. The order of testing was equally split between the officers. At least one week elapsed between tests. Tests included choice reaction time, reaction time to the presentation of an “x” in a string of letters, and haptic sorting of letters and numbers while blindfolded. There was no significant difference in the choice reaction time task. The vigilance reaction times (responses to “x”) were significantly slower and had greater variability after night duty. Haptic sorting was significantly slower after the night duty but there was no significant difference in the number of errors. Choice reaction times were significantly slower for participants after less than five hours of sleep in the last of three blocks of trials.

Andreyka and Tell (1996) compared the task performance of 24 obstetrical residents after being on call for 36 hours (sleep-deprived state) versus before being on call (rested state). There were significant increases in errors of omission and errors of commission in the sleep deprived state. There were also significant differences in both response time and response time variability but the authors did not provide information on the direction of the difference.

Leonard, Fanning, Attwood, and Buckley (1998) compared the performance of 16 interns at the end of either a normal (8- to 10-hour) shift or a 32-hour shift. Testing was conducted between 1600 and 1800 for each group. There was significant degradation in performance of the trail-making test (draw a line between circles with the number 1 to 13 or the letters a to l) and Stroop Color Word test for those who worked the 32 hour shift but no difference in the performance of the delayed story recall, critical flicker fusion, or three minute grammatical reasoning test.

Bartel, Offermeier, Smith and Becker (2004) measured the reaction time and accuracy of 33 resident anesthetists preceding night duty (average 7.04 hours sleep) and 24 hours after night duty (1.66 hours sleep during night duty). Four reaction time tests increasing in complexity (simple, choice, sequential one back, sequential two back) were performed over a 35 minute period. Reaction times were significantly longer after night duty for simple (12%), choice (6%), and one back test (7%). Accuracy was significantly decreased after night duty for both the one (2%) and two back (4%) tests.

Mak and Spurgeon (2004) reported no significant difference between performance at the beginning and at the end of a call day for 21 residents. The task was completion of a complex numeric pattern.

Lingenfelser et al. (1994) compared performance of 40 young doctors after a night off (at least six hours sleep) and after a night on call (in the hospital for 24 hours). Tasks were connecting numbers, recall of a list of items, choice reaction time, Stroop test, and Electrocardiogram simulation. There were significant decrements in the performance of all five tasks.

Some studies measured performance across multiple days. Rollinson et al. (2003) studied the performance of twelve interns working 12 hour consecutive night shifts in an emergency department. Data were collected at the beginning of a day shift and the end of night shifts on day 1 and day 3 of *four consecutive night shifts*. The tests were delayed recognition, vigilance, and the Santa Ana Form Board test. There was a significant decrease (18.5%) in the number correct before first error on the delayed recognition test. Neither of the other two tests had any significant differences.

Klose, Wallace-Barnhill, and Craythorne (1985) measured performance of 14 residents over *five days*. Tasks were digit symbol, card sort, pegboard, and Stroop. There was a significant effect for day with a general increase in score over time. Dula, Dula, Hamrick, and Wood (2001) reported significantly higher scores on the Kaufman Adolescent and Adult Intelligence Test for 8 emergency medicine residents working day shifts compared to 8 working five consecutive night shifts.

Deaconson et al. (1988) evaluated the performance of 26 surgical residents over a *nineteen day period*. These researchers defined sleep deprivation as less than four hours of sleep in the preceding 24 hours. This was determined from a sleep log maintained by the residents. Tasks were paced auditory serial addition, connecting randomly marked points, grammatical reasoning, mentally assembling a geometric figure, and the Purdue Pegboard. There were no significant differences between sleep deprived and non-sleep deprived residents.

Different Participants—Rested Versus Not Rested. Light et al. (1989) compared the performance two groups of surgical residents—21 rested and 21 sleep deprived. There were eight tests. The only significant difference was on the pegboard test with decrements for both the dominant and non-dominant hand when sleep deprived. In a similar study Hart, Buchsbaum, Wade, Hammer, and Kwentus (1987) compared the performance of 16 sleep-deprived and 14 normal first year residents. The tasks were recall from stories, Sternberg short-term memory task and a paced auditory serial addition task. The sleep-deprived residents recalled less information and tended to have longer response latencies on the Sternberg task ($p < 0.10$).

Richardson et al. (1996) reported no effect of sleep loss. Their participants were 26 physicians who either had four hours of protected time for sleep during a 36 hour call day and those who did not. The task was simultaneous tracking with visual reaction time.

Medical Tasks. In an early study of sleep loss, Friedman, Kornfeld, and Bigger (1973) (also Friedman, Bigger, and Kornfeld, 1971) evaluated the performance of 13 male and one female intern. The task was detecting arrhythmias in an electrocardiogram over a twenty minute period. Sleep-deprived participants had an average of 1.8 hours sleep during the previous 32 hours while rested participants had an average of seven hours sleep. The sleep-deprived participants were significantly less able to detect the arrhythmias. Interviews conducted after the task identified difficulties thinking, memory loss, depression, irritability, sensitivity to criticism, depersonalization, and black humor. Christensen, Dietz, Murry, and Moore (1977) compared the nodule detection rate in radiographs for seven rested and seven fatigued residents (i.e., worked at least 15 hours). They reported no significant difference between the two groups.

In another early study, Beatty, Ahern, and Katz (1976) compared the vigilance of six anesthesiologists in a simulated surgical task under rested (following a night of normal sleep) or sleep loss (after a night on duty with no more than two hours of sleep in the last 24 hours) conditions. In addition a letter-search task, a grammatical reasoning task, and a rotated letters task were completed. Performance of the surgical task was poorer for four of the six anesthesiologists. There was no decrement in the letter-search task. However, there was a 23% increase in the time to complete the grammatical reasoning task. The results for the rotated letters task were not presented.

Deary and Tait (1987) compared the performance of twelve residents after a night spent off duty, a night spent on call, and a night spent admitting emergency cases. The tests were digit span, counting backwards from 200 in steps of 13, recall of 23 facts from a read passage immediately after reading the passage, recall of 23 facts from a read passage delayed after reading the passage, sort patient reports into normal and abnormal, and make electrocardiogram assessments. There was only one significant effect—an impairment of immediate recall associated with waiting while on call.

Denisco, Drummond, and Gravenstein (1987) compared the performance of 21 resident anesthesiologists after a night with rest and after 24 hours of in-hospital service. The residents were asked to detect deviations in heart rate (HR) and blood pressure outside defined limits. HR and blood pressure were presented in a 30 minute video tape. Residents were scored 0 to 5 with 5 being detection of the deviation within 10 seconds. One point as subtracted for every 10 seconds in which the deviation was not detected. Responses given before the deviation were scored 0. Residents scored significantly lower when they were fatigues than when they were rested.

Engel, Seime, Powell, D'Alessandri (1987) reported that there was not significant decrement in the clinical performance of seven interns after being on call or not. Performance was the score of an attending physician, an actor playing a patient, or of an intern's write up.

Reznick and Folse (1987) measured performance on a factual recall of basic surgical science knowledge task, concentration ability task requiring identification of abnormal results in laboratory reports, a manual dexterity task requiring closing a simulated wound, and the Purdue Pegboard test. The participants were twenty one surgery residents who performed the tests sleep deprived and rested. There were no significant differences on any of the first three tests. However, participants performed significantly better on the Purdue Pegboard task in the non-sleep deprived condition using the dominant hand. There was no significant sleep state effect using the non-dominant hand. In another recall of medical knowledge study, Stone, Doyle, Bosch, Bothe, and Steele (2000) reported no significant effect on American Board of Surgery In-Training Examination (ABSITE) scores for surgical residents on call the night before the exam and those who were not. The data were from 424 residents in 15 general surgery programs.

Eastridge et al. (2003) compared the performance of a simulated laparoscopic surgery of 35 surgical residents pre-call, on-call, and post-call. There were significantly more errors and a significant increase in time to complete during the post call. However, Jensen et al. (2004) evaluated the effects of sleep deficit on acquisition of laparoscopic skills. Sleep deficit was determined by the self-reported amount of sleep the night before the test. The participants were forty surgical residents. Data were time to complete and number of errors for pegboard, cup drop, rope pass, pattern cutting, endoscopic clip application, and endoscopic loop application. There was not effect of sleep on any measure on any test.

In a field study, Jacques et al. (1990) compared the scores of 353 family practice residents based on total number of hours slept the night before the examination, number of hours worked each week, and the average on-call frequency. These authors reported a significant decrease in scores for decreased sleep the night before and for each year of training with first year residents showing the greatest decrement.

Haynes, Schwedler, Dyslin, Rice, and Kersteain (1995) compared the incidents of postsurgical complications between residents who operated the day after a 24-hour on call period and those who had not been. For the 6,371 cases reviewed there were 351 incidents. There were no significant differences in the two groups. Ellman et al. (2004) reported no significant effect of sleep deprivation when comparing mortality rates, operative, pulmonary, renal, neurological, or infectious complications of sleep deprived and non-sleep deprived surgeons. Sleep deprivation was defined as either performing a case that started between 10 p.m. and 5 a.m. or ended between 11 p.m. and 7:30 a.m. The data were 6751 cases collected over a 9 year period.

Landrigan et al. (2004) compared the number of serious medical errors made by interns working a traditional schedule (24 hour or more work shifts every other night) against a schedule without extended hours but with restricted hours per week. The interns were under continuous direct observation over 2,203 patient days. Interns on the traditional schedule made significantly more serious medical errors (136.0 per 1,000 patient days) than those on the restricted schedule (100.1 per 1000 patient-days, $p<0.001$). The interns on the traditional schedule made more errors in critical care units (193.2 versus. 158.4 per 1,000 patient-days, $p<0.001$), in medication errors (99.7 versus 82.5 per 1,000 patient-days, $p =0.03$), and serious diagnostic errors (18.6 vs. 3.3 per 1,000 patient days, $p<0.001$). Note the seriousness of error was rated by two physicians with no direct knowledge of the interns.

Gottlieb, Parenti, Peterson, and Lofgren (1991) compared performance of 32 internal medicine residents under two schedules. The first was a four day rotation consisting of long call and short call days followed by one non-admitting day. Residents remained in the hospital on long call days. The second was a seven day rotation with 1 long call, 3 short call, and 3 non-admitting days. There were 520 patients seen in the first schedule and 583 seen in the second schedule. A sample of the charts from each group was reviewed and medication errors counted. There were 16.9 errors per 100 patients in the first schedule and 12.0 errors in the second.

Smith-Coggins et al. (1997) evaluated the effects of a literature based program to promote good sleep hygiene on six attending physicians. Performance on three tests were repeated four times across the day—after primary sleep period, beginning, middle, and end of shift. The tests were the PVT, electrocardiogram (ECG) interpretation, and intubation of a mannequin. The researchers compared day and night shift. There were significant differences associated with the education on sleep hygiene, specifically, using more strategies for sleeping during the day including masking daytime noise with a fan, napping before night shifts, changing activity when bored, and reducing ambient temperature when drowsy. For the PVT, median reaction time increased significantly across the night shift. There were no significant differences in ECG interpretation but physicians took longer to intubate during the night shift than the day shift but were faster in the later portions of their shift.

Smith-Coggins et al. (2006) compared the performance of 49 residents and nurses with and without a nap during a night shift. All participants had worked at least three consecutive 12-hour night shifts in the emergency department. The data were collected on night 2 (no nap) and 3 (40 minute nap between 3 and 4 a.m. or no nap depending on group). Both groups performed on the second and third nights at pre, mid, and post shifts. The tasks were the PVT, a probed recall memory task (30 seconds to memorize 6 words), and a computer-based intravenous insertion simulation. They also drove a car simulator post shift for about 40 minutes. The group who napped had fewer lapses during the 7:30 a.m. PVT and reported more quickly on their slowest response than the group who did not nap. For the recall, there was one significant difference—the group that napped had fewer correct responses at 4 a.m. than those who did not a nap. For the catheter insertion, the no nap performed more quickly than the nap group during the preshift interval. There were no significant differences in driving performance between the nap and no nap groups. However, both groups spent about 8% of the drive leaving the road or colliding with an oncoming car.

Nurses. Dorrian et al. (2008) analyzed the self-reported work hours, estimated sleep length and quality, fatigue, sleepiness, stress, errors (frequency, type, and severity), and drowsiness while driving home of 41 Australian full-time nurses in a metropolitan hospital. A total of 1,148 days of information was collected. Thirty eight errors and 38 near errors were reported with the majority of the errors occurring during the morning and day shift, while near errors were distributed through the working hours. There were also 65 reports of observing someone else's error with the majority of these occurring at night. Nurses had significantly more sleep prior to evening shifts than to morning or night shifts. There was significantly less hours of sleep in the preceding 24 hours when errors occurred. Across the 34 nurses who drove to work, there were 70 occurrences of extreme drowsiness and seven near accidents with almost half of these occurring between 0700 and 0900, the end of the night shift. Forty percent of the remaining occurrences of extreme drowsiness and near accidents occurred between 1400 and 1900 peaking at the end of the morning shift (1500).

Scott, Rogers, Hwang, and Zhang (2006) analyzed 14 day log books from 502 critical care nurses in the United States. The nurses logged work, sleep, mood, caffeine intake, problems remaining awake, and errors or near errors made. 86% of the reported shifts included overtime with 4% mandatory overtime. 29% were between 85 and 12.5 hours and 62% equal or greater than 12.5 hours. 65% of the nurses reported problems staying awake at least once during the two week period. 40% of drowsiness and 23% of sleep during work occurred between 6 a.m. and midnight although the most reports of drowsiness and sleep episodes occurred between 2 and 4 a.m. with 12 to 2 a.m. and 4 to 6 a.m. close seconds. 27% of the nurses reported making at least one error and 38% near errors. The risk of making an error was greater when nurses worked 12.5 or more consecutive hours (odds ratio 1.94). A similar result occurred for nurses working more than 40 hours per week (odds ratio 1.93).

Summary from the Literature. Samkoff and Jacques (1991) reviewed studies of the effects of sleep deprivation on residents' performance that had been conducted between 1970 and 1990. They concluded from these studies that vigilance was degraded while manual dexterity, reaction time, and short-term recall were not. In a review of 29 studies reported in the literature from 1994 through 2003, Muecke (2005) concluded that the adverse relationship of fatigue and performance affected older nurses (over 40) more than younger nurses. Further shift work may degrade patient safety as well quality of care especially in critical care settings. In a similar review but of 37 articles, Joffe (2006) concluded that fatigue reduction is critical in reducing medical error. Further a culture change must occur in which sleep management is practiced especially among older physicians. Joffe's specialty was pediatric emergency services. For suggestions on identifying and treating fatigue see Rosenthal, Majeroni, Pretorius, Malik (2008).

B.5 Studies Related to Safety During Drive Home

Connor et al. (2002) examined the drivers and passengers of vehicles driven in the Auckland area of New Zealand between April 1998 and July 1999 who were admitted to the hospital or died as the result of a car crash. Excluded were drivers of heavy vehicles, taxis, and emergency vehicles as well as drivers on lowest functional classification roads. A control group was made up of drivers on roads within the area and not on lowest functional classification roads. All participants rated their sleepiness using the SSS as well as their alertness (on a rating scale of one to seven) immediately before the crash or survey. Drivers with scores of 4 or above on the Stanford scale had an 11-fold risk of injury crash versus those with scores below 4. Furthermore, drivers who reported five or fewer hours of sleep in the past 24 hours had increased risk, with drivers who had three hours of sleep or less having the highest risk. The greatest risk was driving between 2 a.m. and 5 a.m.

Another of the traffic studies was reported by Åkerstedt, Peters, Anund, and Kecklund (2005). Five male and five female shift workers completed two two-hour drives in a high-fidelity, moving–base automobile simulator—one drive after a normal night's sleep and the other after a night shift. Four of the participants did not complete the two hour drive after a night shift due to excessive sleepiness. For the remaining participants there were significantly more accidents after the night shift versus after normal sleep. Since four participants terminated early, the time to first accident or termination was used. Again the results were significant with the time shorter in the night shift group (83 +/- 11.5 minutes) than in the normal sleep group (115.5 +/- 3.0 minutes). There was also a significant increase in the sleepiness rating after the night shift.

In a simulator study, Balkin et al. (2004) measured the math performance of 66 commercial motor vehicle drivers (aged 24 to 62) after nine, seven, five, or three hours' time in bed for four consecutive days. There was a significant increase in the time to complete a serial addition/subtraction task. Further, performance in a driving simulator showed significantly larger standard deviations in lane tracking and larger relative lane position in the sleep restricted conditions than in the baseline (normal) sleep condition.

Finally, Barger et al. (2005) evaluated the relationship of extended work shifts and the risk of motor vehicle accidents among interns. The data were collected from a Web-based survey of 2,737 interns who reported work hours, motor vehicle crashes, and near-misses as well as involuntary sleeping. These authors reported that "every extended work shift that was scheduled in a month increased the monthly risk of a motor vehicle crash by 9.1 percent (95 percent confidence interval, 3.4 to 14.7 percent) and increased the monthly risk of a crash during the commute from work by 16.2 percent (95 percent confidence interval, 7.8 to 24.7 percent)." (p. 125). Further working five or more extended shifts within one month significantly increased the risk of falling asleep while driving or stopped in traffic.

Appendix C Basic Research

Basic research studies were categorized by type of task: vigilance (section C.1), cognitive (section C.2), or psychomotor (section C.3).

C.1 Vigilance Tasks

In basic research fatigue is usually induced by sleep deprivation and vigilance tasks are typically visual reaction time tasks performed at regular intervals throughout the study. Sleep deprivation may consist of 18 to 72 hours without any sleep, with restricted sleep, or after a normal work cycle. The regular intervals typically include every two hours throughout a 24 hour period. Vigilance tasks include the Bakan Vigilance Task, PVT, Wilkinson 4-choice reaction time, or unique simple or choice reaction time tasks. A summary is presented in Table 2-3.

The Bakan Vigilance Task. (Bakan, 1959) has a primary task in which participants press a key when a previously memorized sequence of three digits is presented. The interstimulus interval is 1.5 seconds. The secondary task is to estimate the proportion of numbers to letters presented to the right of the three-digit stimuli. A modified version of this task is described in Dollins et al. (1993).

Cruz, Boquet, Detwiler, and Nesthus (2002) compared the performance of 28 participants ranging from 20 to 55 years of age. Over the three-week study participants completed either a clockwise rotation (24 hours off at each shift rotation and a 48-hour weekend) versus a counter-clockwise rotation (only 8 hours off at each shift rotation and an 80-hour weekend). The participants completed the Bakan Vigilance Task at the beginning and end of each shift as well as three 1.5 hour sessions of the Multiple Task Performance Battery. There was a significant effect on the Bakan Vigilance Task associated with work week (more correct responses during the first than during the second week), session (more correct responses at the beginning than at the end of the workday), and rotation condition by shift ("number of correct responses on the first evening shift was significantly higher for the counter-clockwise rotation condition than the clockwise rotation condition").

The PVT. Developed at Walter Reed Army Institute of Research to assess the effects of prolonged duty times associated with sustained military operations. The participant is instructed "When each stimulus appears, press the side button as fast as you can to see your time in 100ths of a second. Do not jump the gun." The original hand held version (Ambulatory Monitoring Inc., Model PVT-192) was designed by Dinges and Powell (1985) with a palm held version described in Thorne et al. (2005).

Jewett, Dijk, Kronauer, and Dinges (1999) analyzed data from three sleep studies in which 61 participants completed the PVT ten hours after 0, 2, 5, or 8 hours sleep the previous night. PVT performance degraded as the amount of sleep decreased. The largest decrement was between the 2 hours and 0 hours of sleep. Belenky et al. (2003) reported that the recovery of mean speed in the PVT took longest in the three hour sleep condition. This was the condition with the largest number of lapses (reaction times greater than 500 ms). Dinges et al. (1997) measured the performance of sixteen young adults throughout seven consecutive nights of restricted sleep (4 to

5 hours). Performance was measured at 1000, 1600, and 2200. There were significant differences in time of day for PVT with poorest performance at 1000 and best at 2200. The fastest reaction times slowed linearly over the seven days while the lapse frequency increased linearly. Balkin et al. (2004) measured the performance of 66 commercial motor vehicle drivers (aged 24 to 62) after 3, 5, 7, or 9 hours' time in bed for four consecutive days. There were significant decrements in performance on the PVT.

In a sleep restriction experiment, Van Dongen, Maislin, Mullington, and Dinges (2003) examined the performance of 48 participants in one of four sleep restrictions: 4 hours per night for 14 days, 6 hours per night for 14 days, 8 hours per night for 14 days, or 0 hours per night over three days. The participants completed the PVT. There were significant cumulative performance decrements in the 4 and 6 hour sleep conditions compared to the 8 hour sleep condition. Performance in the 4 hour sleep restriction condition was equivalent to that of participants without sleep for two nights.

The Wilkinson 4-choice Reaction Time Task. Developed by Wilkinson and Houghton (1975), it was a hand held cassette tape recorder with four light emitting diodes (LEDs) in a two-by-two configuration. Just below the LEDs were four pushbuttons also in a two-by-two configuration. The task was to press the button that corresponded to the light that was turned on. A light was lit every 120 milliseconds (ms)—either the same light or one of the other three lights. Participants were instructed to respond as rapidly and accurately as possible. Balkin et al. (2004) measured the performance of 66 commercial motor vehicle drivers (aged 24 to 62) after 3, 5, 7, or 9 hours' time in bed for four consecutive days. There were significant decrements in performance on the Wilkinson 4-choice reaction time (speed).

Unique Simple or Choice Reaction Time Tasks. Developed in a laboratory setting, Gillberg, Kecklund, and Åkerstedt (1994) measured the performance on a 28 minute visual vigilance task and an 11 minute reaction time task at 2200, 0200, 0400, and 0600 during a night awake. The six subjects participated for two nights. There were no significant differences between nights in either percent hits on the vigilance task or mean reaction time. However, there was a significant difference across time of the night. For vigilance percent hits at 2200, 2400, and 0200 were high with significant decreases at 0400 and even worse decreases at 0600. Reaction time increased steadily from 2200 to 2400 to 0020 then spiked at 0400 and remained at that level at 0600. McCarthy and Waters (1997) reported significant increases in reaction time for a sleep deprived group of male undergraduates when compared to a non-sleep deprived control group. There were a total of 71 participants in their study. Jaśkowski and Weodarczyk (1997) reported longer simple and choice reaction times of thirteen students from 8 p.m. through 6 a.m. night of sleep deprivation. There was no significant effect on response force.

Balkin et al. (2004) measured the performance of 66 commercial motor vehicle drivers (aged 24 to 62) after 3, 5, 7, or 9 hours' time in bed for four consecutive days. There were significant decrements in performance on a 10-choice reaction time (speed and percent correct) task.

Philip et al. (2004) compared the reaction time of ten males aged 20 to 25 and ten males aged 52 to 63 after controlled normal sleep and after a full night of sleep deprivation. In addition to reaction time the researchers measured the number of lapses, i.e., responses above 500 ms during the ten minute task. There were significant effects of sleep deprivation and time of testing (every two hours from 9 to 19 hours) on both reaction time and number of lapses. There were also significant interactions between time of testing and age as well as between sleep condition and age on both reaction time and number of lapses. For reaction time, older subjects were slower especially in later testing sessions. They also had more lapses especially during the later testing sessions.

Table C-1. Basic Research—Effects of Fatigue on Vigilance

Fatigue	Task	Measure	Effect	Reference
3, 5, 7, or 9 hours sleep	PVT	performance	decrements	Balkin et al. (2004)
3, 5, 7, or 9 hours sleep	10-choice reaction time	speed and percent correct	decrements	Balkin et al. (2004)
3, 5, 7, or 9 hours sleep	Wilkinson 4-choice reaction time	speed	decrements	Balkin et al. (2004)
Hours sleep	PVT	recovery of mean speed	took longest in the three hour sleep	Belenky et al. (2003)
Hours sleep	PVT	number of lapses (reaction times greater than 500 ms)	largest in the three hour sleep	Belenky et al. (2003)
Hours off at each shift rotation and hours weekend	Bakan Vigilance Task	number of correct responses	higher for 8 hours off than 24 hours off	Cruz et al. (2002)
Seven consecutive nights of restricted sleep (4 to 5 hours)	PVT	fastest reaction times	slowed linearly over the seven days	Dinges et al. (1997)
Seven consecutive nights of restricted sleep (4 to 5 hours)	PVT	lapse frequency	increased linearly over the seven days	Dinges et al. (1997)
Two nights without sleep	28 minute visual vigilance	percent hits	decreases at 0400 and even worse decreases at 0600	Gillberg, Kecklund, and Åkerstedt (1994)
Two nights without sleep	11 minute reaction time	reaction time	spiked at 0400	Gillberg, Kecklund, and Åkerstedt (1994)
0, 2, 5, or 8 hours sleep	PVT	performance	degraded as the amount of sleep decreased	Jewett et al. (1999)
4 hours per night for 14 days, 6 hours per night for 14 days, 8 hours per night for 14 days, or 0 hours per night over three days	PVT	performance	decrements	Van Dongen et al. (2003)

Summary. As can be seen from Table C-1, fatigue (as induced by sleep loss) consistently degrades vigilance performance regardless of task (Bakan, PVT, Wilkinson, or unique reaction time task). Decrements include increased reaction time and decreased accuracy.

C.2 Cognitive Tasks

As with vigilance research, fatigue was induced by sleep loss. Cognitive tasks were categorized as information processing, storing into and retrieving from memory, problem solving, decision making, and speech. In some tasks the distinctions among these categories was not clear, for example, is categorization information processing or decision making? In this report decision making was restricted to more complex functions such as defining production rates for a factory assembly line. There were also several studies recording performance on a battery of tasks. These studies are reviewed in a separate section. Again tasks and measures varied as did the length of sleep loss.

Information Processing. Heuer, Spijkers, Kiesswetter, and Schmidtke (1998) compared the performance of eleven men every four hours across three days, the first night of which was sleep deprived. The tasks were responding to a current visual stimulus or predicting one. The effect of day was significant with the reaction times on day three shorter than those on days one or two. Variability increased significantly after the night without sleep. The effect of time on task was significant and largest after the night without sleep. In a recent study, Couyoumdjian et al. (2010) compared performance of 108 university students on two tasks: determine if a visually presented digit was 1) odd or even and 2) larger or smaller than 5. Prior to the onset of each task participants were cued as to which task was to be performed. Half of the students performed after a night's rest and half after a night of sleep deprivation. The authors calculated task switching cost as the difference between the median reaction time for switched tasks minus median reaction time for repetition tasks. There was significantly higher switching cost after sleep deprivation. Reaction times were shorter for repetition trials than for switch trials especially after sleep deprivation. Further there were more errors on switch trials than on repetition trials. Sleep-deprived participants made more errors than those who were not sleep deprived.

Casagrande, Violani, Curcio, and Bertini (1997) reported a significant decrement in performance of a letter cancellation task after one night sleep deprivation. The decrements were significant only in the last three (17:30, 19:30, 21:30) of six trials (every two hours beginning at 11:30). Nesthus, Scarborough, and Schroeder (1998a) evaluated the performance of 27 participants in a weekend sleep deprivation study. Tests were synthetic work, letter search, and four-choice reaction time. The authors reported that older participants had stable performance while younger participants had better overall performance but showed a decline over time. Nesthus, Scarborough, and Schroeder (1998b) compared the performance of 27 participants on a four-choice reaction time task and a letter search task at 4, 10, 16, 22, 28, and 34 hours after waking. There were significant session effects on correct reaction time, percent correct, and number of errors for the four choice reaction time but not on the letter search task. Correct reaction time and errors increased and percent correct decreased. Throughput decreased on both tasks over time.

In a sleep restriction experiment, Van Dongen, Maislin, Mullington, and Dinges (2003) examined the performance of 48 participants in one of four sleep restrictions: 4 hours per night for 14 days, 6 hours per night for 14 days, 8 hours per night for 14 days, or 0 hours per night over three days. The participants completed a digit substitution and serial addition or subtraction task every two hours when they were awake. There were significant cumulative performance decrements in both tasks for the participants in the 4 and 6 hour sleep conditions compared to the 8 hour sleep condition. Performance in the 4 hour sleep restriction condition was equivalent to that of participants without sleep for two nights. In a similar study, Wilkinson, Edwards, and Haines (1966) compared the performance of six enlisted men from 0800 to 1030 on the Wednesday and Thursday of six successive weeks. On the night prior to testing they slept 0, 1, 2, 3, 5, or 7.5 hours. They performed an auditory discrimination task and addition. The number of signals detected increased as the number of hours slept increased. For addition the number of sums per hour increased with hours slept. Further the number of errors decreased with hours slept as well.

Lieberman et al. (2006) evaluated the performance of thirteen male soldiers over a four day sustained operations mission. One of the tasks was matching to a sample. There were significantly more time out errors on this task on days three and four but no difference in the number of correct matches or response time. The task was to indicate which of two 7 x 7 matrices of red and green squares matched one that had been presented 1 or 15 seconds prior. In another pattern task, Ferri et al. (2010) compared the cognitive performance of subjects who were healthy and under age 40 during sleep fragmentation (15 subjects) and non-fragmentation (8 subjects). There were significantly longer reaction times among subjects on day 2 than on day 4 when the figures to be compared were not rotated or reversed or not rotated and mirror imaged portions of the mental rotation task. There were no significant differences in spatial attention, inhibition of return (uninformative cued target slower responses), and Stroop task. Miró et al. (2003) measured time estimation over a sixty hour sleep deprivation period. These authors reported a significant lengthening of time estimations over the 60 hour period; specifically from day 1 to day 2, day 2 to day 3, day 1 to day 3, and night 1 to night 2. Their participants were 30 volunteers aged 18 to 24.

Blagrove, Alexander, and Horne (1995) summarized the results of four sleep loss experiments. All the participants were university students. The tasks were logical reasoning, auditory discrimination task, and finding embedded figures. Fourteen performed the logical reasoning every two hours from 2200 to 1600. Sleep deprived participants had significantly fewer items and fewer answered correctly. Sixteen participants performed the auditory discrimination and finding embedded figures tasks from 1900 to 1100. There was a significant decrement in the sleep deprived participants. In a sleep reduction study (limit of five hours of sleep), thirteen participants performed the logical reasoning task. There was no significant effect of sleep reductions. In the second sleep reduction study, twenty participants were assigned to one of three groups: normal sleep, 4 hours sleep, 5 hours sleep. They performed both all three tasks. For the auditory discrimination the sleep reduced groups did as well as the control except for the first test after sleep reduction started. There were no significant effects on either of the other two tests.

Other information processing tasks also show no effect of fatigue, for example, Dinges et al. (1997) measured the performance of sixteen young adults throughout seven consecutive nights of restricted sleep (4 to 5 hours). Performance was measured at 1000, 1600, and 2200. The task was serial addition. There was no significant effect across days. Linde, Edland, and Bergstrom (1999) measured performance of 12 male students during a 33 hour sleep deprivation and 12 non-sleep deprived. The tasks were coding and completing complex numeric patterns. There were no effects.

Memory. In an early study, Polzella (1975) compared the memory performance of four males and himself over nine consecutive days. Participants were allowed to rest on seven of the days and stayed awake on two nights. Participants were presented one letter or digit at a time and up to 13 of these stimuli in a single series. Afterwards they were presented with a probe stimulus and asked if that probe had been among the stimuli previously presented. Participants were also asked to rate their confidence in that judgment. In addition to sleep loss, Polzella (1975) manipulated the number of stimuli that occurred before (proactive inhibition, 0, 1, 2, or 4) and after (retroactive inhibition, 0, 1, 2, 4, or 8) the probe stimulus. The dependent variable was the sensitivity parameter, d', calculated as the yes-no criterion on the Memory Operating Characteristic. All five participants showed a decrement in d' with sleep loss. For one participant this was significant as was the d' pooled across all five participants. This decrement occurred at all levels of proactive and retroactive inhibition. Although there was no significant effect of sleep loss on reaction time, the reaction times were significantly more positively skewed with sleep loss than rest, i.e., in the distribution of reaction times, the tail to the right of mean was longer than the tail on the left. Polzella further examined this effect by defining lapses as any reaction time at least twice as long as the average reaction time. There were significantly more lapses with sleep loss than with rest. Further there was a significant decrement in recognition memory (hit or correct rejection) in the sleep loss condition. Dinges et al. (1997) measured the performance of sixteen young adults throughout seven consecutive nights of restricted sleep (4 to 5 hours). Performance was measured at 1000, 1600, and 2200. For the probe memory the performance at 1600 was the best. There was not a significant effect across days.

Kim et al. (2001) evaluated the effects of 24 hours of sleep deprivation on performance of the memory portion of the Korean version of the Wechsler Adult Intelligence Scale (K-WAIS). The researchers reported that “memory … decreased after sleep deprivation” (p. 127). Harville, Harrison, and Scott (2006) examined the cognitive performance of 30 United States Air Force officers. Accuracy on a two-back working memory was lowest after 36 hours of sleep deprivation. Babkoff, Mikulincer, Caspy, Kempinski, and Sing (1988) measured the performance of fourteen males over a 72 hour sleep deprivation period. The task was to cross out previously memorized sets of letters (2, 4, or 6 letters) presented in a 16 by 20 matrix. There were significant effects of days of sleep deprivation, hour of the day, and number of targets. Number attempted decreased over time, was lowest for the 6 letter set, and worst 0200 to 0600 on the second and third days as compared to the first day. Similar results were reported for accuracy—lower in the four and six letter versions than in the 2 letter version and lower on the third day than on the first day. Mikulincer, Babkoff, Caspy, and Sing. (1989) measured the effects of 72 hours of sleep loss on performance of a visual search for memorized letters. Their participants were 14 persons aged 22 to 32. They concluded that performance decreased significantly as a function of days without sleep. However, performance was higher in the late afternoon than during the midnight to early morning hours.

Problem Solving. Binks, Waters, and Hurry (1999) compared the performance of 29 undergraduate students after 34 to 36 hours of sleep deprivation with that of 32 undergraduate students who had normal sleep. There were no significant differences between groups for paced auditory serial addition. Harville, Harrison, and Scott (2006) examined the cognitive performance of 30 United States Air Force officers. Tasks included math. Accuracy was lowest after 36 hours of sleep deprivation.

Horne (1988) compared the Torrance Tests of Creative Thinking scores of 12 college students who went 32 hours without sleep and 12 with sleep. For the sleep deprived students there were significant increases in planning time and significant decreases in scores for elaboration, originality, flexibility, and fluency. Similarly, Pilcher and Walters (1997) reported significant decreases in performance of the Watson-Glaser Critical Thinking Appraisal task after 24 hours of sleep deprivation compared to normal sleep. The participants were 44 undergraduate students. Kim et al. (2001) evaluated the effects of 24 hours of sleep deprivation on performance of the Luria-Nebraska Neuropsychological Battery and the calculation and digit span tests of the Korean version of the Wechsler Adult Intelligence Scale (K-WAIS). The researchers reported that "There were no differences in freedom from distractibility, tactile function, visual function, reading, writing, arithmetic and intellectual process function. However, the cognitive functions such as … complex verbal arithmetic function were decreased after sleep deprivation" (p. 127).

Decision Making. Harrison and Horne (1999) compared the performance of ten graduate students with sleep or no sleep during a 36 hour trial. The task was a computer-based simulation of a marketing decision-making game. There were no differences in either profitability or production errors on day 1 between the sleep and sleep deprived conditions, however there was a significant decrease in profitability on the 12 hours in the sleep deprived condition. There was also a significant interaction also for production errors with a greater number of errors for the sleep deprived in the last two sessions. Killgore, Balkin, and Wesensten (2006) measured the decision-making performance of 48 participants aged 19 to 39 years old. The task was the Iowa Gambling Task in which participants select from one of four card decks with different payoff functions. The authors reported more risky behavior in the older participants after two days of sleep deprivation versus the younger participants. Linde, Edland, and Bergstrom (1999) measured performance of 12 male students during a 33 hour sleep deprivation and 12 non-sleep deprived. A task was decision making completed either with or without time pressure. There was no effect.

Speech. Harrison and Horne (1997) evaluated the effects of sleep deprivation on speech. Data were collected from nine participants after 36 hours with sleep deprivation and the same period with no sleep deprivation. In the sleep-deprived condition the participants had a lower total count of correctly vocalized words versus the non-sleep deprived condition. Among the sleep-deprived participants there was a significantly higher proportion of words with semantic similarity, as well as a higher number of adjectives and nouns, at the end of the 36 hour period, compared to 6 or 30 hours into the sleep-deprivation period. These authors reported two studies in the following year (Harrison and Horne, 1998). The first study had 20 participants and the second had 30. Each study divided the participants into non sleep deprived and sleep deprived (34 hours without sleep) groups. There were significantly fewer novel associations among words in the sleep deprived group in the first study.

Kim et al. (2001) evaluated the effects of 24 hours of sleep deprivation on performance of the Luria-Nebraska Neuropsychological Battery. The researchers reported that "receptive and expressive speech … decreased after sleep deprivation" (p. 127). However, Binks, Waters, and Hurry (1999) compared the performance of 29 undergraduate students after 34 to 36 hours of sleep deprivation with that of 32 undergraduate students who had normal sleep. There were no significant differences between groups for verbal production of words beginning with a specified letter.

Battery of Tasks. Some researchers used standardized task batteries. Others did not.

Standardized Task Batteries. Rowe et al. (1992) measured cognitive performance of nine males during two 30 hour sleep deprivation periods: one during bright light (3,000 lux) and one during dim light (100 lux). There were two weeks between sessions. Tasks were from the Walter Reed Performance assessment Battery and the Complex Cognitive Assessment Battery. Composite reaction time and accuracy scores were calculated every two hours that the participant were awake from 12 to 28 hours. There was a significant increase in reaction time over time and a significant increase in variability in accuracy over time.

Pilcher, Band, Odle-Dusseau, and Muth (2007) evaluated the performance of 24 college students over a complete night without sleep. Tasks included those from the Wombat (tracking, 3-D figure rotation, quadrant location (identify which quadrant the next number in a series was located), digit cancelling, and autopilot failure on the tracking task), the Automated Performance Test System ((APTS) code substitution, grammatical reasoning, and math processing), a monitoring and control of a simulated chemical plant, the PVT, and a 38 minute vigilance task to detect "H" when it appeared for 0.5 seconds and ignore distracter letters. Data were collected from 5:30 to 9:30 p.m., 9:45 p.m.to 1:45 a.m., 2:30 to 6:30 a.m., and 6:45 to 10:45 a.m. Wombat scores significantly increased over time which was attributed to learning. There were no significant changes in the APTS tasks. There was a significant decrease in performance on the chemical plant task, on the PVT for an increase in reaction time but not an increase in the number of lapses. There was also a significant increase in reaction time and decrease in accuracy for the vigilance task.

Not Standardized Task Batteries. Ikegami et al. (2009), in a recent study, measured the performance of ten males over a six day period. There was an adaptation day with 7 hour's time in bed followed by a day with sleep deprivation and then four days with 7 hours' time in bed. The tasks were simple addition, paced auditory serial addition, simple words memory, reading span, continuous performance, and card sorting. There were significant differences across days with the baseline day having the poorest performance for all tasks except the card sort. For the sleep deprivation day, the scores on the paced auditory serial addition and reading span were lower than on any other day. Also for that day omission and commission errors on the continuous performance were higher than any other day.

Dorrian, Lamond, and Dawson (2000) had measured performance of 18 participants over a 28 hour period. Tasks were visual comparison, tracking, vigilance, and grammatical reasoning. There were significant decrements in all but visual comparison and grammatical reasoning accuracy. Binks, Waters, and Hurry (1999) compared the performance of 29 undergraduate students after 34 to 36 hours of sleep deprivation with that of 32 undergraduate students who had normal sleep. There were no significant differences between groups for card sorting, categorization, Stroop, and the Wechsler Adult Intelligence Scale Revised.

Neri, Shappell, and DeJohn (1992) evaluated the performance of twelve male United States Marines during a simulated sustained operation consisting of 9 hours of planning, four hours of rest, a 14 hour daytime mission, and six hours of rest. Tests were four choice reaction time, grammatical reasoning, serial add/subtraction, manikin, pattern recognition, and time estimation. For the pattern recognition and manikin tests there were significant linear increases in reaction time for correct responses and in response rate over the experiment. There was also a significant linear increase in error rate for the pattern recognition test. There were no significant differences in time estimation over the experiment. There was a significant decrease in reaction time for the grammatical reasoning test. The serial add/subtract test had high values in reaction time and response rate early and late in the experiment and lower values in between. There were no significant differences in the four choice reaction time tests.

Vrijkotte et al. (2004) evaluated the performance of 17 soldiers on three cognitive tests: 1) working memory (recall of 0, 1, or 2 back letters), 2) logical reasoning (Tower of Hanoi pattern transformation), and 3) vigilance and tracking task. There were significant decrements in performance on all three tests. The degradation was linear in weeks 1 and 3 when soldiers were pushed to their physical limits but irregular in week 2 when mental as well as physical limits were challenged. In a similar study, Lieberman et al. (2006) evaluated the performance of thirteen male soldiers over a four day sustained operations mission. One of the tasks was to repeat a series of twelve key strokes. There was no significant difference over time in either accuracy or time to complete.

Mikulincer, Babkoff, Caspy, and Weiss (1990) reported significant decrements in the performance of persons who engaged in off-task cognitions (as measured by the Thought Occurrence Questionnaire) than those persons who did not. The tasks were visual shape discrimination and logical reasoning. There were in addition significant increases in lapses in the visual shape discrimination over days of sleep loss and from 1600 to 2000 and 0200 to 0600 but only for persons in the high off-task cognitions group. Accuracy increased over the days of the experiment on the visual discrimination task. There was a significant increase in response time of 0.44 second associated with sleep loss. There was no significant effect of sleep deprivation on lapses in the logical reasoning task. There was a significant three way interaction of accuracy on the logical reasoning task—participants were less accurate at 0200 to 0600 and in the 4 letter task than at 100 to 1400 in the 2 letter task. There was a similar three-way interaction for the logical reasoning task—response time was longer between the first and third days at 0200 and 0600 for the 4 letter condition.

In one of the longest duration sleep loss periods, Angus and Heslegrave (1985) required participants to continuously monitor communications over a 54 hour period without sleep. The participants were twelve female students, six were highly physically fit (maximum aerobic capacity ≥ 50 ml/kg/min) and six were not (maximum aerobic capacity ≤ 40 ml/kg/min). In addition to monitoring and responding to communications, participants completed four choice serial reaction time task, simple iterative subtraction, encoding/decoding, complex interactive subtraction, logical reasoning, short-term memory (recall complete string of numbers), auditory signal detection, paired-associate learning task, plotting, and map coordinates. There was a significant decrease in the number of correct responses made per minute on the serial reaction task, the logical reasoning, and the encoding/decoding tasks. There was a significant decrease in the percent correct responses in the auditory signal detection task. For the message processing task (responding to communications), there was an initial improvement it was followed by a significant increase in processing time on this task. The effects on the other tasks performed were not presented.

In a study comparing fatigue to blood alcohol concentration (BAC), Lamond and Dawson (1999) selected participants who were social drinkers but did not consume more than six standard drinks per week. Four tasks were performed: identifying the block in which a visual stimulus appears, unpredictable tracking, choice reaction time, and grammatical reasoning. All participated in three conditions: 28 hour sleep deprivation, 0.10% BAC, and placebo. The placebo had no effect. Alcohol degraded performance on all but one task (identifying the block). Sleep deprivation decreased four of the six measures (choice reaction time and accuracy, grammatical reasoning latency, and tracking). The authors concluded that 20 to 25 hours of sleep decrement was equal to 0.10% BAC. Williamson and Feyer (2000) completed a similar experiment and compared performance of 30 transport employees and 9 Army personnel at 0.1% BAC and up to 28 hours of sleep deprivation. Tasks were Mackworth clock, simple reaction time, tracking, dual task symbol digit, spatial memory, memory and search, and grammatical reasoning. They reported that 16.91 (accuracy symbol digit task) to 18.55 (speed symbol digit task) hours without sleep were equivalent to 0.05% BAC. Further 16.51 (reaction time accuracy) to 18.91 (tracking task) hours were equivalent to 0.1% BAC.

Summary. Some researchers have reported increased time and decreased accuracy associated with fatigue but not on all tasks (e.g., Stroop no effect Ferri et al., 2010) or not consistently. For example, categorization tasks show both decrements (Couyoumdjian et al., 2010) and no effects (Binks, Waters, and Hurry, 1999; Ikegami et al., 2009). Similar inconsistency exists for math (decrements: Harville, Harrison, and Scott, 2006; Van Dongen, Maislin, Mullington, and Dinges, 2003; no decrements: Binks, Waters, and Hurry, 1999; Dinges et al., 1997; Neri, Shappell, and DeJohn, 1992) and logical reasoning (Blagrove, Alexander, and Horne, 1995).

C.3 Psychomotor Tasks

In a seminal study, Dawson and Reid (1997) reported the results of two experiments in which the same forty participants performed a tracking task either after 28 hours of being awake or at 0.10% BAC. Between hours 10 and 26 of sleep deprivation performance decreased 0.74% per hour from the baseline value. Performance at the 0.10% BAC level was 11.6% worse than at baseline. The authors “calculated that the performance decrement for each hour of wakefulness between 10 and 26 hours was equivalent to the performance decrement observed with a 0.004% rise in blood alcohol concentration” (p. 235).

In a study from the Home Appliance R&D Center of Matsushita Electric Works in Osaka, Japan, Nakano et al. (2000) measured the performance of ten male participants on tracking and reaction time tasks over a 19 hour period of sleep deprivation. The midrange of performance variability occurred between 1:00 and 5:00 a.m. while the median in the self-rated sleepiness and alertness occurred around 12:00 am.

Summary. Fatigue degrades tracking performance either performed alone (Dawson and Reid, 1997) or in a battery of tasks (Dorrian, Lamond, Dawson, 2000; Nakano et al. 2000; Pilcher, Band, Odle-Dusseau, Muth, 2007; Vrijkotte et al., 2004; Williamson and Feyer, 2000).

C.4 Summary

Table C-2 summarizes the effects of sleep loss on performance. As can be seen, the majority of the research has been in identifying the effects of sleep loss on cognitive tasks. Less has been done on the effects on physical task performance. Also evident is the diversity of tasks which are degraded by sleep loss. These degradations include both increases in errors and in time to compete tasks. But this is not universal. For example, Beatty, Ahem, and Katz (1976) reported no difference in letter search performance. Lieberman et al. (2006) reported no effect on correct matches. Ferri et al. (2010) found no effect on spatial attention. These three studies suggest that spatial memory may be more difficult to disrupt with sleep loss.

DeJohn, Reams, and Hocchaus (1992) found no effect in visual performance and an improved understanding of speech—although the latter could have been associated with learning. Foushee, Lauber, Baetge, and Acomb (1986)'s improvement in flight simulator performance may also be due to practice. This may also apply to Pilcher, Band, Odle-Dusseau, and Muth's (2007) Wombat score results as well. Another case may be Ikegami et al. (2009)'s no effect on card sort. Time estimation has also been reported to not be affected by sleep loss (Neri, Shappell, and DeJohn, 1992). The effects on driving are also not universal (e.g., Connor, et al, 2002 versus Smith-Coggins et al., 2006). Neither is the effect on the Stroop test; Ferri, et al. (2010) reported no effect on Stroop test while others have found this test to be degraded (Leonard, Fanning, Attwood, and Buckley, 1998). By far the most consistent effect and one of the most studied is the effect of sleep loss on vigilance with a clear preference for the use of the PVT. But vigilance performance is not always degraded (Gillberg, Kecklund, and Åkerstedt, 1994).

So research supports that at least in some cases of sleep loss, humans can't "see straight", can't "think straight", can't "do anything right", can't "seem to pay attention", and can't "lift a finger".

Table C-2. Effects of Sleep Loss on Performance

	Visual	Cognitive	Routine	Vigilance	Physical
Åkerstedt, Peters, Anund, and Kecklund (2005)		More accidents in driving simulator			
Ansiau et al. (2008)		Poorer recall, selective attention			
Balkin et al. (2004)		Increase time to complete serial addition/subtraction task, Increased deviation lane tracking in driving simulator			
Balkin et al. (2004)				Degraded PVT, 10 choice reaction time, Wilkinson four-choice reaction time	
Baranski et al. (2007)		Increase assessment errors and target processing time			
Barnes and Wagner (2009)		Injury rate			
Basner et al. (2008)	Decrease accuracy, Decrease hit rate				
Baulk et al. (2009)				Degraded PVT	
Beatty, Ahern, and Katz (1976)		Degraded simulated surgical test, Increased time to complete grammatical reasoning, No effect letter search			
Beh and McLaughlin (1991)		Degraded grammatical reasoning, vertical addition, and card			

	Visual	Cognitive	Routine	Vigilance	Physical
		sorting			
Belenky et al. (2003)				Recovery on PVT, Increased number of lapses	
Castellani et al. (2006)		Decreased number of correct responses four choice reaction time, Increased number of errors, Increased time out errors on matching task			Degraded squat jump (shallower descent before initiating the jump), repetitive lift (number of boxes lifted decreased), obstacle course (time to complete), and wall
Connor et al. (2002)		Increased risk of traffic injury crash			
Couyoumdjian et al. (2010)		Higher switch cost, More errors			
Danner and Phillips (2008)		Increased crash rate			
Dawson and Reid (1997)		Degraded tracking			
DeJohn, Reams, and Hochhaus (1992)	No effect	Improved understanding of speech			
Denisco, Drummond, and Gravenstein (1987)				Degraded detection of deviations	
Dorrian et al. (2008)		More medical errors			
Ferri, et al. (2010)		Longer reaction time, No effect spatial attention, Stroop task			
Förberg et al. (1975)	Decrease number				
Foushee et al. (1986)		Improved performance flight			

	Visual	Cognitive	Routine	Vigilance	Physical
		simulator, More stable in aircraft handling			
Friedman, Kornfeld, and Bigger (1973)		Degraded detection			
Gillberg, Kecklund, and Åkerstedt (1994)				No effect percent hits on vigilance or mean reaction time	
Gillberg, Kecklund, and Åkerstedt (1996)		Higher speed in driving simulator			
Harrison and Horne (1997)		Lower speech word count, Increased speech semantic similarity			
Harrison and Horne (1998)		Fewer novel speech associations			
Harrison and Horne (1999)		Decreased profitability in marketing game, Increase production errors over time			
Hart et al. (1987)		Less recall, Longer response latencies			
Harville, Harrison, and Scott (2006)		Degraded accuracy math and two-back memory tasks			
Hovis and Ramaswamy (2007)	Degraded color vision				
Ikegami et al. (2009)		Degraded simple addition, paced auditory serial addition, simple words memory, reading span, continuous performance, No effect card sort			

	Visual	Cognitive	Routine	Vigilance	Physical
Jacques, Lynch, and Samkoff (1990)		Degraded score medical test			
Jewett et al. (1999)				Degraded PVT	
Killgore, Balkin, and Wesensten (2006)		More risky behavior on Iowa Gambling Task			
Landrigan et al. (2004)		Increased number of serious medical errors			
Leonard et al. (1998)		Degraded trail making, Degraded Stroop, No effect recall, critical flicker fusion, or grammatical reasoning			
Lieberman et al. (2006)		More time out errors on matching task, No effect on correct matches or response time			
Lieberman et al. (2006)		No difference repeating key strokes			
Lieberman et al. (2006)		Decreased number of correct responses reaction time		Degraded visual vigilance	
Mitchell and Williamson (2000)		More errors vigilance task			
National Sleep Foundation's 2010 Sleep in America poll			Degraded everyday tasks, perform at work, perform household tasks, care for family		
Neri et al. (2002)				Worst PVT between 5:50 and 6:50 am	

	Visual	Cognitive	Routine	Vigilance	Physical
Neri, Shappell, and DeJohn (1992)		Increase reaction time for correct responses on pattern recognition and manikin tests, Increase in error rate for the pattern recognition test, No effect time estimation			
Nesthus, Scarborough, and Schroeder (1998a)		Younger participants decline over time in synthetic work, letter search, and four-choice reaction time			
Nesthus, Scarborough, and Schroeder (1998b)		Correct reaction time and errors increased and percent correct decreased on choice reaction time, Throughput decreased on reaction time and letter search			
Pilcher et al. (2007)		Wombat scores increased over time, No changes Automated Performance Test System, Degraded chemical plant task, increase reaction time and decrease accuracy			
Scott et al. (2006)		Self-reported medical errors			
Smith-Coggins et al. (2006)		More lapses PVT, Quicker catheter insertion, No difference driving			
Thompson, Lopez, Hickey,		Decreased throughput reaction			

	Visual	Cognitive	Routine	Vigilance	Physical
DaLuz, and Caldwell (2006)		time task, Increased error piloting performance			
Van Dongen, Caldwell, and Caldwell (2006)				Degraded pilot performance in simulator	
Vrijkotte et al. (2004)		Degraded recall, reasoning, and tracking			
Welsh et al. (2004)					Degraded peak jump height and power of 1, 5, and 30 repetition unloaded counter movement squat jumps

Appendix D Fatigue Models

This section contains both a review of existing models to measure and analyze fatigue risk as well as an evaluation of modeling techniques from both civilian and military applications. Given that it is already planned for use by FAA, the FAST model is not reviewed. Fatigue models are concerned with a logical or mathematical representation of one, or a combination, of the following (CASA, 2010):

- Objective measures of neurobehavioral performance.
- Subjective assessments of fatigue.
- Fatigue-related task errors.
- Fatigue-related risk of operational accidents.
- Estimated sleep/wake times.

In the aviation domain, fatigue models are critical in the estimation of performance levels of both air and ground crew. The output of these models is used for risk assessment and risk mitigation through scheduling. Such models are intended to move beyond simple flight and duty time limits, and address individual fatigue levels and performance using models which reflect the individual's specific physiology, work, and rest patterns. Generally, these models are used in roster scheduling, and intended for integration into an encompassing FRMS, a methodology for managing fatigue risk using assessment, mitigation, monitoring, training, and education.

Models may be:

- Biomathematical: biologically-inspired equations which predict output variables based on input data such as time of day, workload, etc.
- Rule-based: expert-specified rules which relate input variables to output in an expert system.

The inputs to a biomathematical model are those factors determined to induce fatigue, and they may measure a variety of quantifiable variables. Generally, however, input variables are drawn from the categories of work load (time, amount, type, and regularity), rest availability and quality, circadian rhythms, and circadian disruption. The basic biomathematical model considers a two-process model of sleep regulation: a process that builds pressure for sleep during wakefulness and dissipates this pressure during sleep, and a process that modulates sleep pressure as a function of time of day (Borbély, 1982, McCauley et al., 2009, Borbély and Achermann, 1999). Further developments in fatigue modeling extend this basic model with additional components, including prediction of waking functions, effects of chronic sleep restriction, cumulative duty, time zone shifting, and accounting for unknown initial fatigue states. Validation of such models generally involves Actigraph monitors, surveys, and laboratory studies.

The Australian Civil Aviation Safety Authority (CASA) has published a thorough review of the leading biomathematical models (CASA, 2010). This review covers six models: Circadian

Alertness Simulator (CAS, from Circadian Technologies, Inc., USA), FAID, (from InterDynamics Pty Ltd, Australia), Interactive Neurobehavioral Model (INM, from Brigham and Women's Hospital, USA), Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE™, from Fatigue Science, USA), Sleep/Wake Predictor (SWP, from IPM/Karolinska Institutet, Sweden), and System for Aircrew Fatigue Evaluation (SAFE, from QinetiQ, UK). The SAFE and SAFTE™ models are the most aviation-specific in terms of model inputs. Table D-1, reproduced in part from (CASA, 2010), indicates the various properties of the models reviewed:

Table D-1. Properties of Fatigue Models

Inputs	**CAS**	**FAID**	**INM**	**SAFE**	**SAFTE**	**SWP**
Actual sleep time	●		●	●	●	●
Actigraph data			●		●	●
Sleep schedule	●			●	●	●
Work schedule	●	●		●	●	●
Time zone changes	●			●	●	●
Light exposure	●		●			
Crew type				●		
Sleep in bunks or seats				●		
Take-off and landing waypoints				●	●	
Caffeine dose	●				●	
Model Outputs	CAS	FAID	INM	SAFE	SAFTE	SWP
Objective neurobehavioral metric	●		●	●	●	●
Subjective alertness metric	●	●	●	●		●
Fatigue risk metric	●	●		●	●	●
Estimated sleep/wake times	●			●	●	●
Confidence intervals	●				●	●

In addition to the traditional biomathematical models, there is the Crew Fatigue component of the FORAS (US Naval Research Laboratory). This model is based on expert-specified inference rules relating a wide range of input factors to work load and rest measurements, and an overall relative fatigue assessment (Hadjimichael, 2009). As an expert system representing expert knowledge, to date FORAS has been validated only with respect to the expert-supplied relative risk rankings. In contrast to the biomathematical models, FORAS is less accurate and specific in its estimation of fatigue levels, but broader in its scope of inputs and consideration of long-term cumulative fatigue influences.

While fatigue models have advanced greatly in the past 20 years, there is still need for improvement:

- Integration of the best components of each model into a unified model. Research over the years has focused on various aspects of the model, resulting in many improvements, but the lack of a clearly dominant, fully encompassing model.
- Better integration of irregular duty schedules and other aviation-specific conditions. Besides SAFE, SAFTE™, and FORAS, no other models of fatigue/risk reflect the specific issues related to aviation.
- Better integration of age and other individual physiological characteristics. Most models deal in average physiological responses, and don't include a method for modeling the specific characteristics of the crew of a single flight, although the most recent research is beginning to address individualization using Bayesian methods (United States Department of Transportation [USDOT], 2009).
- More research and modeling of long-term (year-long) cumulative fatigue. Besides FORAS, no model discusses the work load and stresses that result from crew roster schedules which compress the bulk of a legal year's flying into, for example, the first part of the year.
- Clear understanding of the connection between alertness levels and performance in an aviation setting. Biomathematical models of alertness can yield very precise theoretical numbers, but the connection to performance is not always well understood or modeled.
- Extension of fatigue-performance links in non-flight crew aviation. Other areas of concern are ATC and ground crews.
- Validation of fatigue risk using actual aviation performance data, such as Digital Flight Data Recorder (DFDR) data. To date, the correlation between DFDR data and fatigue estimates has been challenging, at least partially due to the restricted availability and sensitivity of those data.

Appendix E Fatigue Countermeasures

Two types of mitigation are described: 1) short-term countermeasures (section E.1) and 2) FRMSs (section E.2).

E.1 Short-term Countermeasures

Stimulation in the environment can help to alleviate mental fatigue (Cebola, Kilner, 2009; Signal, 2002; Straussberger, 2006). This can include physical stimulation (music, lighting, fresh air), internal stimulation (caffeine and stimulants), or social stimulation. Stimulation can also be amplified by increasing task motivation. Variation in the task or environment should also be provided to minimize the effects of fatigue. Cognitive stimulation can promote alertness through varying the complexity of the task, the activity required by the task, and the mode (active vs. passive monitoring). During monotonous and repetitive situation, short rest periods (5 minutes) are more effective than one long rest period (30 minutes). If sustained performance is required (greater than 6 hours) a short nap (15 minutes) should help rejuvenate an individual. Cumulative fatigue is refers to fatigue that is caused by the quantity and quality of sleep (Rosekind et al., 1996a). The only countermeasure for cumulative sleep is to achieve adequate rest. Shift fatigue is fatigue that increases during the shift (Cebola, Kilner, 2009).

Countermeasures for fatigue include (Rosekind et al., 1996a; Rosekind et al., 1996b; Cebola, Kilner, 2009; CAA of New Zealand, 2000; Salazar, 2007; Caldwell, 1997):

- Napping
  - Less than 45 minutes or around 90 minutes (or a multiple of 90) to minimize sleep inertia effects
  - Restricted to early morning (1-5 a.m.) or mid-afternoon (1-3 p.m.)
  - Useful prior to a midshift
- Avoiding alcohol, caffeine and nicotine 3 to 6 hours before bed
- Limiting alcohol and caffeine consumption
- Obtaining 8.5 hours of continuous sleep each day
- Sleeping in an conducive environment
  - Appropriate bedding
  - Comfortable temperature
  - Put phone on silent
- Utilizing blackout curtains and/or eye masks when sleeping during daytime hours
- Avoiding carbohydrates until the end of a shift

- Consuming healthy meals while working (proteins, fruits, and vegetables will increase alertness)
- Avoiding a large meal after work if one is going to sleep soon after
- Stretching regularly (at least every hour) to improve circulation
- Working out 2-3 before bedtime
- Developing a pre-sleep routine
- Getting to sleep the same time each night
- Utilize mental relaxation techniques to help sleep
- Not using sleeping pills
- Knowing side-effects of medications that may cause fatigue or affect alertness

Other Tips:

- See a doctor if you have sleep problems, there may be an underlying condition
- After lying in bed for 30 minutes, if sleep escapes you, get up and try reading or listening to music and then return to bed once tired

Environmental Factors for Fatigue Avoidance (Occupational Safety and Health Administration [OSHA], 1999):

- Humidity range of 20-60%
- Temperature range of 68-76 degrees Fahrenheit
- 20 cubic feet per minute of outdoor fresh air whose source is not near contaminants, for every occupant in an office
- removal of contaminants with either filters, or electronic or chemical cleaners

Long-term shift work can result in serious disruptions of the circadian rhythm that can manifest in feelings of fatigue. These disruptions can be combated with bright-light exposure during the night, but for this to work, shiftworkers would also have to have uninterrupted sleep in a dark environment during the day (Küller, 2002). With shiftworkers who work rapidly rotating shifts, like controllers, it would probably be best to use bright light to improve alertness without the goal of circadian rhythm shift (although they would still be affected to some degree) (Cajochen, 2007).

E.2 Fatigue Risk Management Systems

There has been a shift away from HOS rules and towards FRMSs. FRMSs are in use across various industries, including nuclear power plants, aviation, ATC, rail, mining, trucking, and emergency services, among others. For an FRMS to be effective in the long-run, the culture of the industry/organization has to change (Stein, 2009). In 1995 it was acknowledged that the problem was not that technology for mitigating risk could not be developed, but that getting organizations and employees to accept the technology was (Dinges, 1995). Table E-1 contains a list of organizations that currently have FRMSs implemented or are investigating FRMSs, separated by ones that the FAA has previously reviewed (in order to avoid duplication of effort), ones that are reviewed in the following sections of this appendix, and a list of organizations (of the lead author) that are investigating/utilizing FRMSs, but that enough information regarding the FRMS could be found to include in the review.

Table E-1. FRMSs

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E.2.1 Australia

In addition to ATC, FRMSs have been put in place for mining. Defenses in Depth has also been applied.

Mining. ARRB Transport Research developed a real-time monitor that measures operator alertness levels during a shift for haul truck drivers on mining sites. The ARRB Fatigue Monitoring Device is part of the ARRB Pro-Active Fatigue Management System which also incorporates employee fatigue training and employee fatigue management profiles which contain their performance data from the device as well as data from take-home sleep research equipment. The profiles can be used for performance monitoring and the initiation of countermeasure discussions with individual employees where appropriate (Mabbot, 2003).

The ARRB Fatigue Monitoring Device detects lowered alertness and intervenes to counter fatigued drivers through the measurement of reaction times to visual and auditory stimuli. The reaction involves pressing a button with the direction of where the stimulus was (either left or right). The device presents stimuli at random 7 to 10 minute intervals when the truck is in motion, but not when the parking brake is engaged or when the truck is reversing. If the reaction is slow or incorrect, the interval will reduce to 4 to 7 minutes. If the reaction time is again slower, the stimuli will present at 2 to 4 minute intervals and the supervisor back at the control room will be notified via the radio link and should make contact with the driver to discuss countermeasures that may be undertaken. If reaction times are extremely slow or the stimuli are missed all together, a warning buzzer will emit in the truck and the stimuli will present every minute until the supervisor contacts the driver; at this point the driver should not drive until after a nap has been taken. The ARRB reportedly reduces costs by preventing fatigue accidents/incidents, increasing driver performance, improving vehicle care (better rested drivers appear to treat their vehicles better), and is a way of meeting fitness-for-duty regulatory requirements (Mabbot, 2003).

The ARRB Pro-Active Fatigue Management System was found by the Australian Coal Association Research Program to offer the industry a way to proactively monitor driver fatigue and manage it successfully (Mabbot, 2003).

In 2008, Worksafe Victoria and Industry and Investment New South Wales (NSW) published a guide entitled *Fatigue Prevention in the Workplace* as a guide to assist employers in complying with occupational health and safety laws regarding fatigue. The guide explains how demands of work, schedules, work duration, work environment and individual factors can all influence fatigue and what can be done to reduce the risk of fatigue. The guide includes an explanation of fatigue as well as the factors inside and outside of work that contribute to it and the short and long term effects of fatigue on performance and health. It discusses a risk management approach to fatigue, including identifying it as a hazard, analyzing its interaction with other hazards, assessing and controlling the risks associated with fatigue, and uses case studies to illustrate fatigue risk instances and appropriate controls (WorkSafe Victoria and WorkCover NSW, 2008).

A detailed chart based on Appendix 2 of the *Fatigue Prevention in the Workplace* guide was also developed. The chart includes hazard identification, risk assessment and risk control. The hazard identification column includes mental and physical demands; work scheduling and planning—

night work; work scheduling and planning—shift work; work scheduling and planning—hours; excessive commuting times necessary; work environment conditions; individual and non-work factors. The risk assessment column shows the risks of the associated content below each section in the hazard identification column on a scale from low, moderate to high risk with a description of what would be consider low, moderate and high. The risk control column then includes options for risk control (Industry and Investment NSW, 2008).

The NSW Mine Safety Advisory Council's Fatigue Working Party developed a *Fatigue Management Plan*, which is a guide for the development and successful implementation of a fatigue management plan into the mining/extraction industries. The guide includes an explanation of fatigue and discussion of the fatigue problem. It states that every mine has to conduct a fatigue risk assessment, and those that are required to have a documented fatigue management plan that is available for audit include mines whose schedules: have more than just a day shift; have more than 48 hours in a consecutive five day period; or that do not provide minimum two consecutive days off in a seven day period; as well as mines where a fatigue hazard has been identified during the assessment (NSW Mine Safety Advisory Council's Fatigue Working Party, 2009). The guide has an example structure and approach for a fatigue management plan that can be modified according to the particular mine. During the development process, consultation with employees is legally required. It is stressed that all of the mine employees have to make a commitment to the plan and that the plan needs to be reviewed and revised frequently to keep up with changing aspects of the industry of specific mine, including, but not limited to, proposed scheduling changes (NSW Mine Safety Advisory Council's Fatigue Working Party, 2009).

Defenses in Depth. Defenses in Depth manages fatigue as part of an organization's Safety Management System (SMS) and takes a multi-level approach to preventing fatigue-related accidents rather than a single-level approach that HOS limits take by acknowledging that fatigue accumulation and recovery is not linear. The Defenses in Depth approach sees a fatigue-related accident/incident as being the result of an error trajectory and was developed for use in aviation as well as other industries (Dawson and McCulloch, 2006). See Figure E-1.

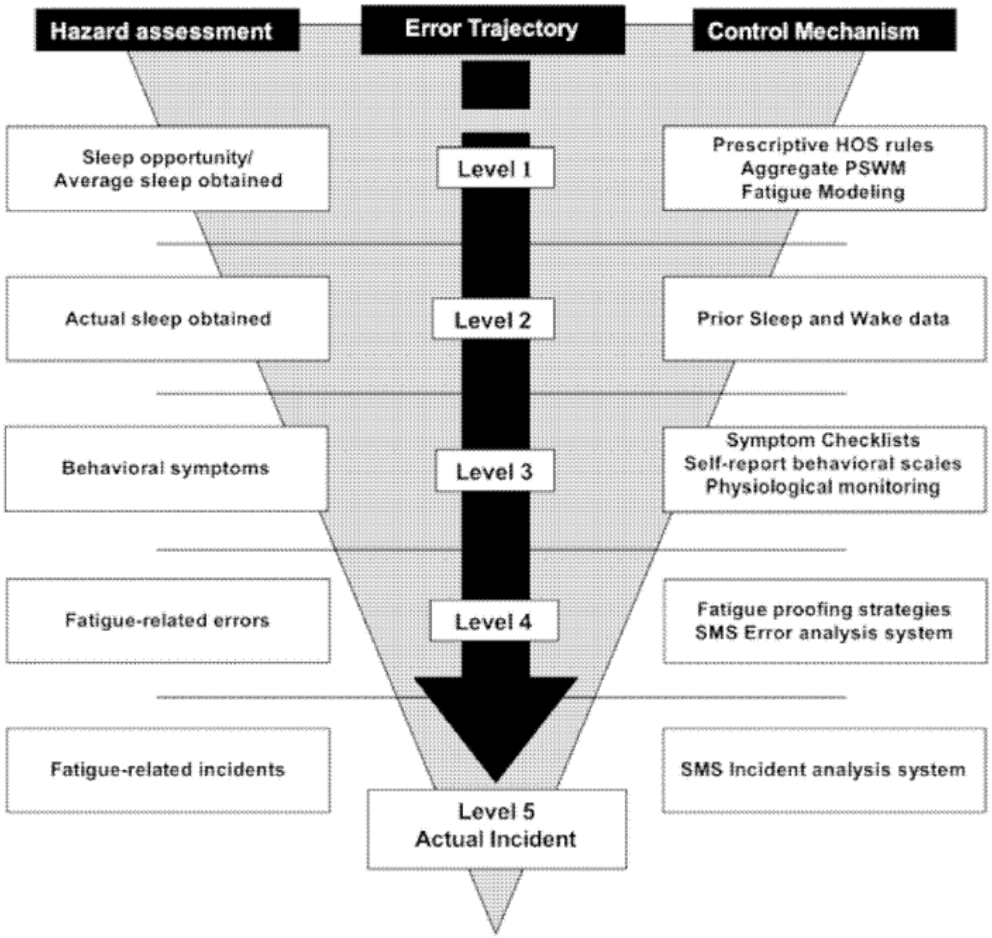

Figure E-1. Defenses in Depth Approach[6]

The error trajectory is insufficient recovery sleep due to either a sleep disorder, or activities that limited sleep time or an inadequate break period that did not allow for enough sleep that causes insufficient sleep or extended wakefulness that leaves the employee in a fatigue-state during which he or she exhibits fatigue related behaviors, causing him or her to make fatigue-related errors, which lead to a fatigue-related accident/incident (Dawson and McCulloch, 2006). The researchers suggest that at level one of the error trajectory, employers have to make schedules that are conducive to employees getting adequate sleep; at level two, employers need to have a way to confirm that adequate sleep was indeed obtained; at level three, employers need to ensure that those employees who had an opportunity for and obtained adequate sleep do not exhibit fatigue-related behaviors; at level four, employers need to identify and keep track of fatigue-related errors that do not lead to accidents/incidents; and at level five, employers need to

[6] Source: Dawson, D., K. McCulloch, 2006, "Managing Fatigue: Defenses in Depth," Proceedings of the Joint Meeting of the FSF 59th annual International Air Safety Seminar IASS, IFA 36th International Conference and IATA: Enhancing Safety Worldwide, Oct 23-26, Paris, France, Alexandria, VA: Flight Safety Foundation.

investigate all fatigue-related accidents/incidents to determine the cause and where the FRMS failed (Dawson and McCulloch, 2006).

Predictive models of fatigue are acknowledged to be useful for assessing schedules, but will not provide defenses past level one, as they do not take into account individuals differences and daily variations and rather predict overall average levels of fatigue. Dawson and McCulloch suggest that a FRMS should assess prior sleep and wake of employees. The Prior Sleep Wake Model (PSWM) is an algorithm that consists of three variables: x = the hours of sleep the employee has obtained in the previous 24 hours before a shift, i = the sleep the employee has obtained in the previous 48 hour before a shift, and z = the time that the employee will have been awake for at the end of the shift. Variables x and y make up the Prior Sleep Threshold and x, y, and z make up the Prior Wake Threshold. The thresholds would have to be determined according to industry and task and likely would vary, however, the researchers acknowledge that if z exceeds $x = y$, the employee likely would be at an increased risk of making a fatigue-related error (Dawson and McCulloch, 2006). The control mechanisms that Dawson and McCulloch recommend for the levels on the error trajectory include HOS rules at level one, PSWM at level two, checklists at level three, analyses of errors and near-misses at level four, and accident/incident analyses at level five that investigate levels one-four (Dawson and McCulloch, 2006).

The Defenses in Depth approach has been applied in the medical industry in Australia within Queensland Health. They published the *Fatigue Risk Management Resource Pack* and distributed it to all their entities to help them develop, design, and implement a FRMS. They suggest perhaps using FAID to assed the fatigue-risk in different schedules at level one. Use of the PSWM at level two is recommended, and an example fatigue score calculator is included. Use of a subjective scale, such as the Samn-Perelli Fatigue Checklist is suggested for use at level three. Level four involves analyzing errors and near-misses of fatigue-related accidents/incidents. A schematic of feedback's role in an ever-evolving Defenses in Depth Framework is included (Queensland Health, 2009). See Figure E-2.

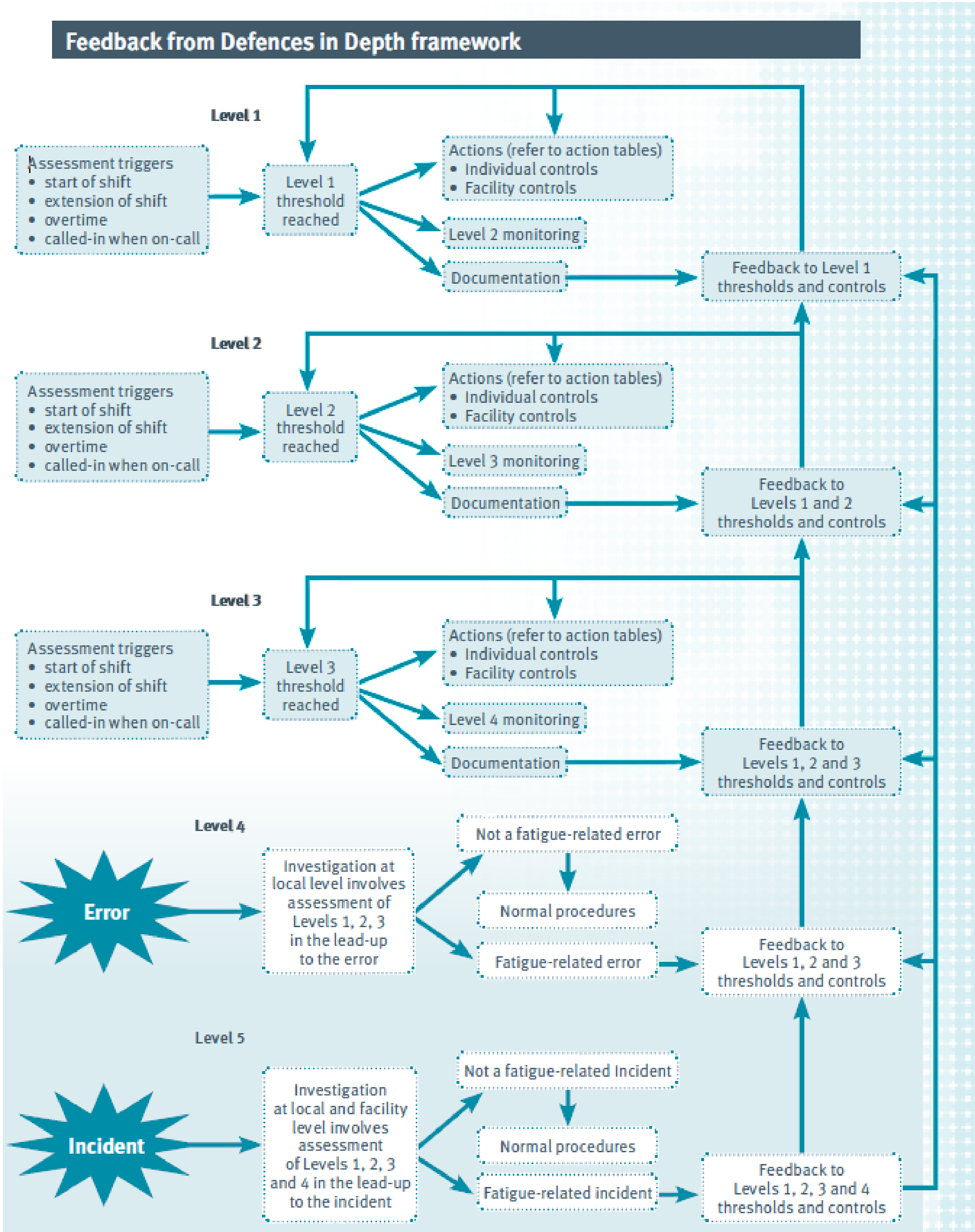

Figure E-2. Defenses in Depth Framework[7]

[7] Source: Dawson, D., K. McCulloch, 2006, "Managing Fatigue: Defenses in Depth," Proceedings of the Joint Meeting of the FSF 59th annual International Air Safety Seminar IASS, IFA 36th International Conference and IATA: Enhancing Safety Worldwide, Oct 23-26, Paris, France, Alexandria, VA: Flight Safety Foundation.

E.2.2 France

Airlines. In France in 2008, EU-OPS, which develops safety regulations/procedures for revenue passenger and cargo operations, changed the flight time limitations regulation in Europe and introduced the FRMS idea, allowing an FRMS for reduced rests (a rest period less than the 11 hour requirement), split duty, and extended flight time. The Direction générale de l'Aviation civile (DGAC) (translated: Directorate General of Civil Aviation) initiated a project entitled STARE (Sécurité du Transport Aérien et gestion du Risque fatiguE) (translated: Air Transport Security and Fatigue Risk Management) with three regional airline participants to research FRMS implementation in regional airlines in France. The goal of the project is to develop a FRMS that will reduce fatigue risk beginning at the scheduling level (by using predictive fatigue models), monitor the schedule by analyzing Air Safety Reports (ASR), Flight Data Monitoring (FDM), and sick leave data, and investigate the root causes of trends related to fatigue that are observed in the data, through the utilization of various in-flight data collection as well as surveys (Cabon et al., 2008; Cabon et al., 2009). Preliminary results indicate that accumulated fatigue should be considered when scheduling aircrew, and that time of day is a significant factor in fatigue and that ASR and FDM data could potentially be used to evaluate schedule's effect on fatigue (Cabon et al., 2009). The FRMS being developed will be incorporated throughout an airline, into the scheduling process and training of aircrews and schedulers. Additionally, the FRMS will enable the airlines to monitor their fatigue risk daily, as well as predict the effect any significant change in scheduling will cause, and also analyze fatigue's role in accidents (Cabon et al., 2008; Cabon et al., 2009).

E.2.3 New Zealand

In New Zealand in 2000, the accident database said that only 0.2% of aviation accidents or incidents were fatigue-related. This was believed by the CAA's Manager of Safety Analysis and Manager of Safety Investigation to be a gross underestimation and to be more likely around 25%. The statistic was thought to be low because of the voluntary nature of the database and that the person filing the report would have had to recognize that fatigue was a factor before they could report it. The CAA felt they needed to ask questions that would elicit fatigue information that could have contributed to the accidents/incidents that are reported (CAA of New Zealand), 2000). However, a check of the occurrence report for accidents and incidents revealed no questions that would elicit fatigue information (CAA of New Zealand, 2009). Also, at the Fatigue Risk Management Issue Assessment Group's (IAG) meeting on May 24, 2010, a lack of a fatigue reporting system was identified and the need to develop one as part of a FRMS was noted (Fatigue Risk Management Issue Assessment Group, 2010).

Airlines. In 1995, the CAA of New Zealand began to allow FRMSs in place of flight and duty limitations with Amendment 1 of CAR Part 121. The current regulations, as of 25 March 2010, for fatigue in flight crew are located in CAR Part 121, Air Operations—Large Aeroplanes, Subpart K—Fatigue of Flight Crew (for aircraft with either greater than 30 seats (not including crew member seats) or a payload greater than 3410 kg); CAR Part 125, Air Operations—Medium Aeroplanes, Subpart K—Fatigue of Flight Crew (for aircraft with either 10-30 passenger seats, or a payload of 3410 kg or less, or a maximum certified takeoff weight of 5700 kg or more, or a single-engine plane operating under instrument flight rule (IFR) conditions); CAR Part 135, Air Operations—Helicopters and Small Aeroplanes, Subpart K—Fatigue of Flight Crew (for aircraft with 9 seats or less and a maximum certified takeoff weight of 5700 kg or less, (unless operating Single Engine Instrument Flight Rules (SEIFR)), and helicopters).

Within Subpart K of CAR Part 121, 121.803 Operator responsibilities states, in short, that an operator cannot operate flight operations unless they have developed a “scheme” that has been approved by the director that addresses the 21 factors listed in 121.803 (a)(2), which includes such factors as rest before flights, time zones, dead-heading, cumulative duty and flight times, circadian rhythm, days off, and in-flight relief. Additionally, 121.803(b) says airlines may not let someone who appears to be fatigued to fly and 121.803(c) states the operator must keep records of every crew member’s flight and duty times for 12 months after the record is made. In 121.805 Flight Crew responsibilities, 121.805(a) requires that fatigued crew members do not fly, (b) do not fly other hire or reward flights if they have exceeded the flight and duty limitations in the airlines “scheme,” (c) do not exceed the limitations in the scheme, and (d) do not exceed 100 flight hours in 28 consecutive days nor 1000 flight hours in 365 consecutive days (CAR Part 121, 2010).

Within Subpart K of CAR Part 125, 125.803 Operator responsibilities is identical to 121.803. 125.805 Flight crew responsibilities is identical to 121.805 (CAR Part 125, 2010). Within Subpart K of CAR Part 135, 135.803 Operator responsibilities is identical to 121.803, except for a few minor word changes that do not affect the message. 135.805 Flight crew responsibilities (a), (b), and (c) are identical to 121.805 except a few minor word changes that do not affect the message. However, 135.803 (d) differs in that it does not have the limitations for hours flown in 28 and 100 days and instead is a provision allowing for flight even if limitations of the scheme have been or will be exceeded if the flight is “made in the interests of safety or health of any person” (CAR Part 125, 2010, pg. 80) and the pilot-in-command deems the exceeded limitation of the crew member not to be a threat to the safety of the flight (CAR Part 135, 2010). In 2006, an Advisory Circular, “Air Operations—Fatigue of Flight Crew” was published to give an example to the airline industry of a FRMS that would receive the approval of the director of the CAA (CAA of New Zealand, 2006).

A report in 2006 investigated fatigue management in the New Zealand Aviation industry among operators with a 119 certificate, which in New Zealand is what allows for the transportation of passengers or goods for hire. Among those with a 119 certificate, there are 121 (large aircraft), 125 (mid-size aircraft) and 135 (small aircraft and helicopters) operations. Every operator with a 119 was sent three surveys, one each to be filled out by an employee in a managerial role, a rostering role, and a line pilot role. The survey elicited information about the operating organization including its operating rules, aircraft fleet, organization size, and role of the person filling out the survey. It also asked questions regarding the fatigue management strategies that were in use by the operating organization and examples (for instance, education, monitoring of workload, monitoring of flight and duty times, accident/incident occurrence reporting, identification and management of fatigued employees, the review process for the strategies and if feedback was taken into account, and whether rostering software was used for scheduling). As well as how flight and duty time regulations were followed and how well the operating organization managed fatigue. Additionally, the following information was requested who was responsible in the operating organization for the fatigue management, where the operating organization gathered information on fatigue management, the effects of the fatigue management strategies in place in the operating organization, the problems with fatigue management and resources that would be helpful against these problems. Of the 52% respondents, 60% of 121 and 125 operators, and 28% of 135 operators reported having more than eight fatigue management strategies in place. Of these strategies, 70% of 121, 50% of 125, and 23% of 135 operators reported using rostering software for scheduling. 80% of 121, 70% of 125 and 44% of 135 operators reported having an accident/incident reporting system with fatigue as an option. 60% of 121, 100% of 125 and 68% of 135 operators reported having a process for the identification of fatigued employees (Signal, Ratieta, and Gander, 2006).

In terms of who was in charge of fatigue management at the operating organizations, at 121 operators is was generally a Flight Operations Manager or group of employees; at 125 and 135 operators, it was usually a CEO, Chief Pilot, or Flight Operations Manager, or a mix. In regards to where the operating organizations gathered information or their fatigue management, most organizations said either they did not; from common sense; or not applicable. Others cited publications, industry bodies, New Zealand CAA documents and regulations, and company policy documents. Positive effects of fatigue management included safety, and negative effects included less flexibility. Most operating organizations did not have report having any problems or barriers related to fatigue management, but some cited costs or staff issues, among other issues. The considerable amount of the operating organizations said they did not need any resources or help, but those that did said they would want more education on the subject as well as knowledge sharing among different operating organizations (Signal, Ratieta, and Gander, 2006).

The examples of fatigue management strategies in place ranged from integrated training courses to a detailed review of flight and duty time limitations and/or company policies regarding flight/duty time. The authors felt that the training course was a good viable idea, but that a detailed review of policies was alarming because it does not help employees understand the causes, symptoms, and consequences of fatigue, and may lead them to believe that as long as the limitations are followed, they will not experience fatigue. It also showed that the industry at large probably had an insufficient understanding of the fatigue issue. The authors of the investigation and report recommended that the CAA needed to appoint someone or some organization to increase awareness surrounding the fatigue issue (Signal, Ratieta, and Gander, 2006).

E.2.4 United Kingdom

Aviation. A compact disc (CD) with a reference document (Visual and Manned Performance in Illumination Reduced Environments (VAMPIRE)) was made and given to aviators to remind them of the extra risks associated with flying at night after Britain acquired the Apache helicopter, which was primarily going to be flown at night. Pre-made slide presentations were also provided to trainers.

A basic assessment tool (BAT) provided in Excel was also developed and included in the guide which can serve as a tool for predicting one's objective fatigue factor and give him or her an indication of what variables might impact his or her performance and supplement his or her decision making. However, it is not validated and was not to be used as an absolute indicator of an aviator's fatigue. The BAT asks questions regarding pervious mission in the last 24 hours as well as the fatigue factor that had been calculated for that mission. Sleep debt information is elicited by asking the amount of sleep in the prior 24, 48, and 72 hours. The number of time zones away from home base and how many days the person has been away from it are asked. Information regarding other pertinent variables that can affect fatigue are requested including if the mission is between 3 and 5 a.m.(the nadir of the circadian rhythm), if the aviator will be continuously awake for more than 16 hours at the end of the mission, if the mission is a night mission, if chemical/biological protection is worn, if night vision equipment is used, if the person is in an extreme environment, if the person is in a field environment, if the person has done strenuous activity for more than 30 minutes the day of the mission, if the person has napped in the last eight hours, and how long the mission will be. The author felt that the BAT would be useful in planning missions by determining who in the crew was the least fatigued, could be used in educating aviators about the factors that can affect fatigue and also felt that it could be easily adapted to other setting including fixed-wing operations, rail, trucking, nuclear power plants, hospitals, emergency services, and ATC (King, 2005). Follow up articles regarding this tool could not be found.

Petroleum/Related Industries. Kingsley Management Group developed *Improving Alertness Through Effective Fatigue Management* in cooperation with The Energy Institute. It is divided into four sections, the first being an introduction section that uses case studies to define fatigue and its causes and to identify fatigue's health and safety consequences as well as problems with the management of fatigue. Section two describes risk factors that must be controlled for to prevent fatigue including HOS, shift duration, time of shifts, commuting time, age, breaks within and between shifts, shift rotation patterns, sleeping patterns, working conditions, workload, and variables that can affect the sleep/wake cycle (i.e. sleep disorders, medications). The third section uses a marine case study to help illustrate risk assessment and accent investigation and discuss the two elements of safety management systems, identifying and controlling for hazards; and investigating and learning from accidents to prevent from repeats in the future. It also provides an assessment/investigation checklist. Section four contains a checklist for use in evaluating if an organization has a fatigue problem, and options for follow up investigation after an identification of a fatigue problem are included with their pros and cons. Solutions for reducing fatigue are associated with specific factors are presented in a table. The document also stresses need for management and workforce to be educated on fatigue and alertness and how to implement solutions and track their effectiveness (Gall, 2006; The Energy Institute, 2006).

E.2.5 United States

FRMSs have been applied in emergency services, nuclear power, and rail.

Emergency Services. A city police department implemented a FRMS "Operation Healthy Sleep" to screen for and treat obstructive sleep apnea (OSA) and provide sleep hygiene information to police officers. The goal was to reduce fatigue's detrimental effects on performance, health, and safety of officers. Operation Healthy Sleep was provided to half of the departments in a district. It began with an educational session on sleep hygiene, caffeine, and OSA for all officers (approximately 70% attended (n=1126)), who afterwards were asked to participate in the research. Those who volunteered completed a screening survey for OSA to identify which officers were at-risk (682 volunteered, but only 662 completed the survey), and 34% (n=222) of those who completed the survey were determined to be at risk. 146 of those identified as at risk were evaluated by a sleep physician and/or ApneaLink™ portable monitoring device if the physician decided it was appropriate, 18 subsequently dropped out of the study and 20 were not referred for treatment. 100 of the 108 officers who were referred for CPAP treatment (they either had an apnea-hypopnea index (AHI) >10 or an AHI >5 with daytime symptoms) started treatment. The FRMS was successful at identifying a large amount of previously undiagnosed officers with OSA. Complete results and analyses are as of yet unavailable (Lockley et al., 2009).

Nuclear Power. Regulations on work hours for nuclear personnel are found in 10 Code of Federal Regulations (CFR) Pt. 26 (Fitness for Duty Programs, 2010). 10 CFR Pt. 26 Subpart I--Managing Fatigue, contains the requirements for fatigue management of nuclear power plant personnel of licensees that are authorized to operate a reactor under 10 CFR 50.57, as well as some authorized under 10 CFR Pt. 52 and others as stated in 10 CFR 26.201 Applicability, which they must meet I before they will receive nuclear material. 10 CFR Pt. 26 Subpart I—Managing Fatigue and takes into consideration numerous factors that can influence fatigue and not just work hours, including such variables as sleep disorders and circadian rhythm variations. Information regarding the policies, procedures, training, recordkeeping, reporting and auditing of the fatigue management program are found in 10 CFR 26.203.

10 CFR 26.205 sets the caps of work and break durations. Employees cannot work more than 16 hours in 24 hours, 26 hours in 48 hours, or 72 hours in 7 days. Additionally, they must be given a minimum of a 10 hour break between duty periods or 8 hours if necessary due to shifts/scheduling (10 CFR 26.205(2)(i)); and a 34 hour break in 9 days (10 CFR 26.205(2)(ii)). Personnel who work 8 hour shifts must have 1 day off per week (10 CFR 26.205(3)(i)), those who work 10 hour shifts must have 2 days off per week (10 CFR 26.205(3)(ii)), and those who work 12 hour shifts must have 2, 2.5, or 3 days off per week depending on the duties they perform (10 CFR 26.205(3)(iii-v) (these are averaged over the shift cycle, which may not exceed six weeks). 10 CFR 26.205(4-6) has amended work hour requirements for outages and associated situations. 10 CFR 26.205 also includes what may and may not be included in the calculation of employees' work hours. Shift turnover that is necessary for a safe transfer including discussion of equipment and operational status may be excluded (10 CFR 26.205 (1)). Work done during emergency drills (10 CFR 26.205 (4) and incidental work done off-site (such as a telephone call) (10 CFR 26.205 (5) may not be included. Holdovers for late employees on the next shift or investigations; and early arrivals for briefings, meetings, or training must be included in the calculation (10 CFR 26.205 (1). Additionally, breaks are included, unless they provide for a nap (10 CFR 26.205 (2)).

10 CFR 26.207 outlines procedures for waivers of 10 CFR 26.205. 10 CFR 206.209 provides guidance for what must be done when an employee declares him or herself as not fit for duty due to fatigue. He or she either must be relieved immediately, unless that is not possible, in which case he or she must be relieved as soon as possible (10 CFR 26.209(a)). After an employee declares him or herself as unfit, he or she should either be reassigned to other duties until has a fatigue assessment done under 10 CFR 26.211 that shows he or she will be able to perform the

activities safely (10 CFR 26.209 (b)(1)) or be allowed/required to take a 10 hour break before returning to his or her original duties (10 CFR 26.209 (b)(2)).

10 CFR 26.211 requires a fatigue assessments to be performed for cause; after a self-declaration; after an event; and to follow-up if less than 10 hours is taken after a self-declaration or after a for cause assessment (10 CFR 26.221(a)(1-4)). 10 CFR 26.211 also lists who may conduct assessments and timeframes for their conduction as well as what must be addressed in the assessment (acute fatigue, cumulative fatigue, and circadian variations (10 CFR 26.211(c)(i-iii)) and documentation and records required.

The U.S. Nuclear Regulatory Commission (USNRC) published Regulatory Guide 5.73, Fatigue Management for Nuclear Plant Personnel in March 2009 which defines a method to comply with 10 CFR Pt. 26 (USNRC, 2009). It endorses NEI 06-11 [Revision 1] Managing Personnel Fatigue at Nuclear Power Reactor Sites, published by the Nuclear Energy Institute (NEI) in October 2008 (NEI, 2008), except for various additions, exceptions and clarifications as described in Regulatory Guide 5.730.

Rail. Fatigue has been cited as the probable cause in two rail accidents. A collision between a Union Pacific Railroad train and a BNSF Railway Company train was determined to have a probable cause of crew fatigue on the Union Pacific train that stemmed from inadequate restorative sleep due to both the employee’s activities while off-duty and the scheduling practices of Union Pacific (NTSB, 2006). Another accident involving two Canadian National/Illinois Central Railway trains was determined to have a probable cause of crew fatigue, stemming from the engineer’s untreated, and the conductor’s insufficiently treated, OSA, on one of the trains (NTSB, 2002).

Rail employees have had HOS rules mandated by a congressional statute since 1907. HOS rules only address how much work is performed, but do not take into account when (during the day/circadian rhythm) and how many consecutive days work is performed. These variables as well as duration of time off between shifts, medical conditions that contribute to fatigue, and others factors need to be integrated to appropriately manage fatigue’s risk in the rail industry through a FRMS that includes education and training (Federal Railroad Administration (FRA), 2006). The FAST has been shown to be able to assess work schedules’ relationship to fatigue and accompanied increased rail accident risk (Hursh, Raslear, Kaye, and Fanzone, 2006). In 2006, a review of fatigue risk management in the rail industry concluded that FAST or an equivalent tool needed to be used to evaluate and subsequently implement FRMSs in the rail industry (FRA, 2006).

New HOS rules went into effect on July 16, 2009 after the Rail Safety Improvement Act of 2008 was enacted on October 16, 2008. Carriers cannot allow train employees to continue duty, start duty, wait for or in deadhead transportation from an assignment to the place of release, or performing any other mandatory work for the carrier after an employee has spent 267 combined hours in a calendar month: on duty, waiting for or in deadhead transportation to their place of final release, or performing other mandatory work for the carrier. Also, the carrier cannot allow a train employee to be on duty for more than 12 hours; be on duty or start duty unless they have been off for 10 consecutive hours in the preceding 24 hours; be on duty or start duty after they have worked six consecutive days, unless they have had 48 consecutive hours off at home, nor;

be on duty or start duty after they have worked for seven consecutive days, unless they have had 72 consecutive hours off at home, (however, there are various exceptions and stipulations to these maximums). Train employees also may not spend 40 cumulative hours in a calendar month waiting for or in deadhead transportation to their final place of release. While employees are off-duty, the carrier may not contact them as this can disrupt rest (49 U.S.C. § 21103).

Signal employees cannot be on duty for more than 12 hours and may not work unless they have had 10 consecutive hours off in the preceding 24 hours. While signal employees are off on their 10 consecutive hours of rest, the carrier may not contact them (49 U.S.C. § 21104). Dispatching employees cannot be on duty for more than 9 hours in a 24 hour period in a setting with two shifts; and no more than 12 hours in a 24 hour period in a setting with one shift (49 U.S.C. § 21105). The limits on hour and rules on no contact are modified or lifted in case of emergency (49 U.S.C. § 21103-§ 21105).

According to the Rail Safety Improvement Act, as part of the Railroad Safety Risk Reduction Program (49 U.S.C. § 20156) that requires all Class I railroad carriers, carries that have been determined by the Secretary to have insufficient safety performance, and carriers that provide passenger or commercial intercity transportation to have an approved safety reduction program within four years of the act being enacted, a fatigue management plan must be developed, updated, and approved by the Secretary every two years. The fatigue management plan should be tailored to specific employees and parts of the rail system, and must include up-to-date employee training on human factors and physiological factors of fatigue and countermeasures. It also must include ways to identify and treat employees with sleep disorders or other medical disorders than can cause fatigue. It must include procedures for employees who have been in emergencies or other fatiguing activities; scheduling practices that reduce sleep loss and debt; procedures that minimize accidents during periods of the circadian rhythm that have been linked to increased accidents; alertness strategies to combat fatigue while on duty, possibly including napping policies; environments for restful sleep provided by the carrier; increase consecutive hours of off-duty rest where the employee when be unreachable by the carrier; avoid disrupting employee’s rest cycles; and anything else the Secretary determines must be involved. However, 49 U.S. C. § 21109. (a) allows the Secretary to create regulations that reduce maximum duty hours, increase minimum times between shifts, limit or eliminate time waiting for, or receiving, deadhead transportation as well as limit or eliminate the travel time from an off-site worksite after the employee’s scheduled work hours, and/or the travel time from a trouble call back to the carrier site or to the employee’s home, and; increase release periods for signal employees. Finally, the Secretary can require changes to scheduling, operating, and on-call procedures of operators that may affect employee fatigue. Also to note, 49 U.S.C. § 22109. (b) allows for the Secretary to develop regulations regarding HOS for commuter and intercity passenger carriers that may be different from the ones defined in chapter 122 within three years of the enactment of the Railroad Safety Improvement Act of 2008 (Rail Safety Improvement Act of 2008). The Railroad Safety Improvement Act of 2008 may be accessed at http://www.fra.dot.gov/downloads/Pub.%20L.%20No.%20110-432%20in%20pdf.pdf.

E.2.6 FRMS Recommendations for Fatigue Management

A 1996 document article in *Behavioral Medicine* authored by NASA, San Jose State University Foundation, and Sterling Software employees discussed an integrated approach for fatigue management. They recommended that education should include an explanation of the causes of fatigue, misconceptions about fatigue, and countermeasures to fatigue and include relevant examples for the specific industry in which the management framework is deployed. For aviation, the NASA/FAA Alertness Management in Flight Operations series was recommended. The authors cited the need for physicians and other health care personnel to be better trained in recognizing symptoms of sleep disorders. Also, it was suggested that rest and duty schedules take into account all aspects of a job, physiological considerations, and current research regarding fatigue, and not just union contracts and economics (Rosekind et al., 1996b).

A manual for fixed rotating schedules was developed by the Air Force Research Laboratory. The nine principles and components that are identified as underlying good shiftwork schedules are: circadian stability; short shift; minimum consecutive nights; recovery after night shifts; maximum free weekend days; 104 days off per year; equity regarding types of work and days off; predictable schedules; quality time off. The manual states that number of work days and days off as well as the sequence should be considered when scheduling. Circadian rhythm, times conducive for sleep, fatigue related to time-on-task and workload, as well as the opportunity for recovery sleep were all included as variables that need to be considered when scheduling. Other suggestions were that regular start and end times are better than irregular and that rush hour should be avoided when scheduling. When to start night and morning shifts was identified as a lose-lose situation because finishing the night shift earlier and thus allowing for better sleep for the night workers would cause the morning workers to have to wake up earlier and encroach on their sleep time (Miller, 2006).

E.2.7 Gaps

How to control for fatigue in ATC in the U.S. is still a gap, as currently there is no FRMS in place. For the FRMS to work, it must be accepted and enforced across all levels of ATC. The Defenses in Depth framework seems like an appropriate place to start developing a FRMS for U.S. ATC. Analyzing the different schedules currently used with FAID of SAFTE™ would be a first step and could be the level one defense mechanism. Use of a PSWM could be the level two defense mechanism, however, sufficient education to the employees regarding how to spend their time away from work to get sufficient sleep for their shift must be provided. A level three defense mechanism could be a short checklist at the beginning of the shift to determine fitness-for-duty. When a fatigue related error occurs, even when an accident/incident does not, it should be analyzed to see where the FRMS failed. Also, a standard investigation framework for fatigue-related accidents/incidents should be developed. Appropriate auditing of the FRMS needs to be done to hold facilities accountable and ensure that the culture is accepting the FRMS.

The largest gaps in risk analysis for FRMSs were: 1) evaluation of joint effects of multiple factors in addition to fatigue, 2) longitudinal studies on individuals over years to identify the long-term effects of cumulative fatigue, and 3) data on how to tailor FRMSs to specific populations.

Appendix F Survey from the Nation-wide Shiftwork & Fatigue Survey

INSTRUCTIONS

The attached survey asks questions about your shift schedule and aspects of your shiftwork experience. Some individuals receiving this survey are not currently working shiftwork. Please respond to this survey based on your current schedule and experience.

We are grateful for your time and participation.

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Appendix G Fatigue Measures

Acquiring a measurement of an individual's level of fatigue is complicated. While fatigue may be ubiquitous in the literature and in life, a measurement method of fatigue, in itself, has yet to be adequately developed and scientifically validated. Currently, fatigue is measured through subjective questioning (asking individuals if they are experiencing fatigue, tiredness, sleepiness), and objective measures such as physiological measures, and secondary state measures (e.g., workload, performance, SA).

Edu.au Pty. Ltd. was commissioned by AirServices Australia to review physiological and psychological scientific research regarding fatigue, particularly research relevant to air traffic. The review found that objective measures of fatigue like cognitive or psychomotor tests are better than subjective measures. In regards to sleep parameters, actigraphy (which can overestimate sleep) is better than subjective ratings like sleep diaries, but the best option for objective measurement is electroencephalogram (EEG) (van den Heuvel et al., 2003).

Current research efforts being led by Dr. Melissa Mallis of the Institutes for Behavior Resources, Inc. (IBR), including the four publications cited in her presentation on August 4, 2010 for the Article 55 Working Group are not included in this report. These four publications are Dinges and Mallis (1998), Mallis and Dinges (2005), and Mallis, Banks, and Dinges (2007; 2010).

G.1 Subjective Measures of Fatigue

Subjective measures rely on the impression or perception of the individual completing the test/survey/questionnaire. These ratings may be influenced by an individual's mood, desire to please, interest or opinions on the topic being tested or their perception of the task. Results from subjective tests may be erroneous due to the participant's desire to answer 'correctly' or by the participant's lack of interest in the experiment. Subjective testing may also be skewed by the words that are used to declare a question (positive/negative phraseology), the individual's opinion on what the words mean, and the participant's ability to understand and follow directions. Subjective measures can also be time consuming and have a tendency to interrupt tasks. Despite the problems that come with subjective measurements, they are still a very important and much needed research method. Subjective measures help to inform researchers about the underlying mental processing that is occurring during a task. Surveys and questionnaires are the most direct method of identifying how a participant is feeling (e.g., alert, sleepy, bored, annoyed), how the task is influencing their actions and performance, and what is needed to help the participant succeed. It is also important to differentiate physical and mental fatigue (Gawron, French, and Funke, 2001). A somewhat dated but very thorough review of subjective fatigue scales prior to 2005 is presented in Dittner, Wessely, and Brown (2004). A more recent review is presented by Shahid, Shen, and Shapiro (2010).

The following questionnaires have been used extensively to measure fatigue:

- **Brief Fatigue Inventory (BFI).** The BFI has nine items to assess the severity of fatigue and its impact in the past 24 hours. Each item is rated on an 11 point scale. The BFI has been validated on cancer patients only (Mendoza et al., 1999).

- **Chalder Fatigue Scale (CFS).** The CFS was developed to measure fatigue severity and gives an overall fatigue score by measuring mental fatigue and physical fatigue. The original scale had six mental fatigue questions and eight physical fatigue questions, for a total of 14 questions. The revised scale has only 11 questions (four mental, seven physical). It has been scored bimodally and on a Likert scale (Chalder, Berelowitz, Pawlikowska, Watts, Wessely, Wright, Wallace, 1993). Reliability is high for both subscales (mental = +0.086, physical = +0.85). It differentiated fatigued and non-fatigued employees (Beurskens et al., 2000) and chronic fatigue syndrome patients from the general population (Cella and Chalder, 2010). The two subscales were found to be valid (Morriss, Wearden, and Mullis, 1998). Internal consistency is also high (+0.89) (Chalder et al., 1993; +0.978, Ferentinos, Kontaxakis, Havaki-Kontaxaki, Dikeos, and Papadimitriou, 2010). The 11-tems are:

Physical symptoms

1. Do you have problems with tiredness?
2. Do you need to rest more?
3. Do you feel sleepy or drowsy?
4. Do you have problems starting things?
5. Are you lacking in energy?
6. Do you have less strength in your muscles?
7. Do you feel weak?

Mental symptoms

8. Do you have difficulty concentrating?
9. Do you have problems thinking clearly?
10. Do you make slips of the tongue when speaking?
11. How is your memory?

The scale responses are

1 = not at all
2 = no more than usual
3 = more than usual
4 = much more than usual

- **Checklist Individual Strength (CIS).** CIS was developed as a chronic fatigue measure and measures four dimensions, subjective feelings of fatigue, reduced motivation, reduced activity, and reduced concentration. In 2000, it was determined to be a valid instrument for fatigue measurement of the working population (Beurskens et al., 2000; Bültmann, Kant, Kasl, Beurskens, and van den Brandt, 2002; Kant et al., 2000; Kant et al., 2003). The CIS contains 20 statements that are rated on a seven point Likert scale from ‘yes, that is true’, to ‘no, that is not true’ for experiences in the preceding two weeks before completion on the questionnaire. The twenty statements are:

1. I feel tired
2. I feel very active

3. Thinking requires effort
4. Physically I feel exhausted
5. I feel like doing all kinds of nice things
6. I feel fit
7. I do quite a lot within a day
8. When I am doing something, I can concentrate quite well
9. I feel weak
10. I don't do much during the day
11. I can concentrate well
12. I feel rested
13. I have trouble concentrating
14. Physically I feel I am in a bad condition
15. I am full of plans
16. I get tired very quickly
17. I have a low output
18. I feel no desire to do anything
19. My thoughts easily wander
20. Physically I feel in a good shape

Items 2, 5, 6, 7, 8, 11, 12, 15, 20 are scored as follows:

Rating	Yes, that is true 1	2	3	4	5	6	No, that is not true 7
Score	1	2	3	4	5	6	7

Items 1, 3, 4, 9, 10, 13, 14, 16, 17, 18, 19 are scored as follows:

Rating	Yes, that is true 1	2	3	4	5	6	No, that is not true 7
Score	7	6	5	4	3	2	1

The score for each subscale is simply the sum of the scores for the particular items associated with the subscale.

Subscales and Corresponding Item Numbers		
Subscale 1	Subjective feeling of fatigue items	1, 4, 6, 9, 12, 14, 16, 20
Subscale 2	Concentration items	3, 8, 11, 13, 19
Subscale 3	Motivation items	2, 5, 15, 18
Subscale 4	Physical activity items	7, 10, 17

- **Crew Status Survey.** The original Crew Status Survey was developed by Pearson and Byars (1956) and contained 20 statements describing fatigue states. The staff of the Air Force School of Aerospace Medicine Crew Performance Branch, principally Storm and

Parke, updated the original survey. They selected the statements anchoring the points on the fatigue scale of the survey through iterative presentations of drafts of the survey to aircrew members. The structure of the fatigue scale was somewhat cumbersome, since the dimensions of workload, temporal demand, system demand, system management, danger, and acceptability were combined on one scale. However, the fatigue scale was simple enough to be well received by operational crews. The fatigue scale of the survey was shortened to seven statements and subsequently tested for sensitivity to fatigue as well as for test/retest reliability (Miller and Narvaez, 1986). It has been used extensively in military fatigue research (e.g., Neville, Bisson, French, Boll, and Storm, 1994). Finally, a seven-point workload scale was added. The current Crew Status Survey (see Figure G-1) provides measures of self-reported fatigue and workload as well as space for general comments. Ames and George (1993) modified the workload scale to enhance reliability. Their scale descriptors are:

(1) Nothing To Do; No System Demands.
(2) Light Activity; Minimum Demands.
(3) Moderate Activity; Easily Managed; Considerable Spare Time.
(4) Busy; Challenging But Manageable; Adequate Time Available.
(5) Very Busy; Demanding To Manage; Barely Enough Time.
(6) Extremely Busy; Very Difficult; Non-Essential Tasks Postponed.
(7) Overloaded; System Unmanageable; Important Tasks Undone; Unsafe. (p. 4).

NAME	DATE AND TIME

SUBJECT FATIGUE

(Circle the number of the statement which describes how you feel RIGHT NOW.)

1	Fully Alert, Wide Awake; Extremely Peppy
2	Very Lively; Responsive, But Not at Peak
3	Okay; Somewhat Fresh
4	A Little Tired; Less Than Fresh
5	Moderately Tired; Let Down
6	Extremely Tired; Very Difficult to Concentrate
7	Completely Exhausted; Unable to Function Effectively; Ready to Drop

COMMENTS

WORKLOAD ESTIMATE

(Circle the number of the statement which describes the MAXIMUM workload you experienced during the past work period. Put an X over the number of the statement which best describes the AVERAGE workload you experienced during the past work period.)

1	Nothing to do; No System Demands
2	Little to do; Minimum System Demands
3	Active Involvement Required, But Easy to Keep Up
4	Challenging, But Manageable
5	Extremely Busy; Barely Able to Keep Up
6	Too Much to do; Overloaded; Postponing Some Tasks
7	Unmanageable; Potentially Dangerous; Unacceptable

COMMENTS

SAM FORM APR 81 **202** **CREW STATUS SURVEY**

PREVIOUS EDITION WILL BE USED

Figure G-1. Crew Status Survey

- **Daytime Sleepiness Scale (DSS).** The DSS has eight items each rated as never (0), rarely (1), sometimes (2), or often (3). Scores are sums of these ratings with 0 to 10 as normal.

Johnson, Breslau, Roth, Roehrs, and Rosenthal (1999) reported an internal consistency of 0.71. Levine, Roehrs, Zorick, and Roth (1988) used the DSS to measure daytime sleepiness in young adults.

- **Epworth Sleepiness Scale (ESS).** The ESS was developed by Johns (1991) and asks participants to rate how likely they are to fall asleep on a scale from 0 (never doze off) to 3 (high chance of dozing) in eight different situations (Johns, 1994b). Scores are the sum of the responses and have a high test-retest reliability (+0.82)(Johns, 1994a). They are also sensitive to changes associated with treatment of sleep apnea (Johns, 1991, 1992).
- **Fatigue, Anergy, Consciousness, Energized and Sleepiness (FACES).** FACES is a list of 50 adjectives to measure five subscales. It was validated at six Canadian sleep clinics (Shapiro et al., 2002). The items are:

1. Fatigue subscale
    a. Fatigued
    b. Worn out
    c. Exhausted
    d. Wacked out
    e. Drained
    f. Pooped
    g. Overtired
    h. Weary
    i. Tired
    j. Spent
    k. Bushed
    l. Out of steam
    m. Frazzled
    n. Limited endurance
    o. Achy muscles
2. Anergy subscale
    a. Indolent
    b. Languid
    c. Soporific
    d. Supine
    e. Accidie
    f. Phlegmatic
    g. Line of least resistance
    h. Jaded
    i. Apathetic
3. Consciousness subscale
    a. Comatose
    b. Unconscious
    c. Dormant

d. Bombed
e. Blurry eyed

4. Energized subscale
    a. Vigorous
    b. Full of pep
    c. Lively
    d. Charged up
    e. Energetic
    f. Carefree
    g. Active
    h. Cheerful
    i. Alert

5. Sleepiness subscale
    a. Snoozy
    b. Sleepy
    c. Drowsy
    d. Slumber
    e. Heavy eyed
    f. Half-awake
    g. Yawning
    h. Dozy
    i. Somnambulant
    j. Sluggish (Shapiro et al., 2002).

- **Fatigue Assessment Inventory (FAI).** The FAI consists of 29 items spread across four subscales: fatigue severity, situation specificity, psychological consequences, and response to rest/sleep (Schwartz et al., 1993). Its internal consistency ranges by subscale from 0.70 to 0.92. Its test-retest reliability is moderate (0.29 to 0.69).

- **Fatigue Assessment Scale (FAS).** The FAS was developed to assess chronic fatigue. It is a one-dimensional scale consisting of 10 items that are scored on five point Likert scale, with 1 being 'never' and 5 being 'always' (Michielsen, De Vries, and Van Heck, 2003). The 10 items are shown below.

    1. I am bothered by fatigue
    2. I get tired very quickly
    3. I don't do much during the day
    4. I have enough energy for everyday life
    5. Physically, I feel exhausted
    6. I have problems to start things
    7. I have problems to think clearly
    8. I feel no desire to do anything
    9. Mentally, I feel exhausted
    10. When I am doing something, I can concentrate quite well

- **Fatigue Impact Scale (FIS).** This scale has 40 items covering fatigue impacts on cognitive, physical, and psychosocial function (Fisk et al., 1994). It has high internal consistency (0.87) and has been validated in two patient populations: hypertension and multiple sclerosis.
- **Fatigue Severity Scale (FSS).** The FSS is one of the most widely used measures of fatigue. It is a nine-item scale developed to measure disabling fatigue and has been used extensively in insomnia research (Krupp, LaRocca, Muir-Nash, and Steinberg, 1989). It has high internal consistency (+0. 89) (Loge, Ekeberg, and Kaasa, 1998). Participants rate fatigue from 1 (no fatigue) to 7 (severe fatigue).
- **Fatigue Symptom Inventory (FSI).** The FSI was developed to identify the severity, impact, and duration of fatigue in women with breast cancer (Hann et al., 1998) but has been expanded to all cancer patients. Hann, Denniston, and Baker (2000) however reported low test-retest reliability.
- **Functional Assessment of Cancer Therapy (FACT).** The general version of FACT (FACT-G) has 34 items to assess quality of life in chronically ill patients. The fatigue subscale (FACT-F) has 13 items, good internal consistency (0.93), as well as test-retest reliability (0.90) (Yellen, Cella, Webster, Blendowski, and Kaplan, 1997). It has not been validated on populations outside of patients.
- **General Fatigue Scale (GFS):** Meek, Nail, and Jones (1997) reported high internal consistency and reliability among cancer patients. Schwartz et al. (2002) reported sensitivity to increases in fatigue over time.
- **Karolinska Sleepiness Scale (KSS).** The KSS is a nine point scale developed by Åkerstedt and Gillberg (1990). Participants rate their level of sleepiness experienced in the last 10 minutes. Kecklund and Åkerstedt (1993) reported increases KSS scores with increased time awake. Kaida et al. (2006) reported strong correlations between KSS score and EEG activity.
- **Maslach Burnout Inventory Emotional Exhaustion Subscale (MBI-EE).** The MBI has three subscales to measure burnout: emotional exhaustion, depersonalization, and personal accomplishment. The MBI-EE measures emotional exhaustion in burnout and includes nine items. Maslach and Jackson (1986) define emotional exhaustion as low = 0 to 16, moderate = 17 to 26, high = 27 and above. Maslach and Jackson (1986) reported reliability of +0.90 for the EE subscale. A manual is available (Maslach, Jackson, and Leiter, 1996). Schaufeli, Bakker, Hoogduin, Schaap, and Kladler (2001) reported the scale had high validity. Poghosyan, Aiken, and Sloane (2009) reported high subscale reliability in data of 54,738 nurses in 646 hospitals in 8 countries. However, Barnett, Brennan, and Gareis (1999) concluded from interviews with 141 physicians and their spouses who had completed the MBI, that feelings are not adequately assessed and response categories are not mutually exclusive. The subscales are:

1. Emotional Exhaustion (EE)
    a. I feel emotionally drained from my work?
    b. I feel used up at the end of the workday?
    c. I feel fatigued when I get up in the morning and have to face another day on the job?
    d. Working with people all day is really a strain for me?
    e. I feel burned out from my work?
    f. I feel frustrated by my job?
    g. I feel I'm working too hard on my job?
    h. Working with people directly puts too much stress on me?
    i. I feel like I'm at the end of my rope?
2. Depersonalization (DP)
    a. I feel I treat some patients as if they were impersonal objects?
    b. I've become more callous toward people since I took this job?
    c. I worry that this job is hardening me emotionally?
    d. I don't really care what happens to some patients?
    e. I feel patients blame me for some of their problems?
3. Personal Accomplishment (PA)
    a. I can easily understand how my patients feel about things?
    b. I deal very effectively with the problems of my patients?
    c. I feel I'm positively influencing other people's lives through my work?
    d. I feel very energetic?
    e. I can easily create a relaxed atmosphere with my patients?
    f. I feel exhilarated after working closely with my recipients?
    g. I have accomplished many worthwhile things in this job?
    h. In my work I deal with emotional problems very calmly? (Weiss, Silady, and Roes, 1996, p. 640).

- **Multidimensional Fatigue Inventory (MFI).** The MFI is a 20 item scale measuring general fatigue, physical fatigue, mental fatigue, reduced motivation, and reduced activity (Smets et al., 1995). The MFI has good internal consistency (+0.84) based on data from cancer patients, psychology students, medical students, physicians, and Army recruits. A sample of the scale items follows:

1. I feel fit	yes, that is true	□□□□□□□	no, that is not true
2. Physically I feel only able to do a little	yes, that is true	□□□□□□□	no, that is not true
3. I feel very active	yes, that is true	□□□□□□□	no, that is not true
4. I am not up to much	yes, that is true	□□□□□□□	no, that is not true
5. Thinking requires effort	yes, that is true	□□□□□□□	no, that is not true

- **Piper Fatigue Scale (PFS).** The PFS is a 41 item scale measuring the affective, intensity, sensory, and temporal dimensions of fatigue (Piper et al., 1989). Concurrent validation was low based on data from 42 patients.
- **Sleep Wake Activity Inventory (SWAI).** The SWAI has 59 items each rated on a scale of 1 (behavior always present) to 9 (never present). The rating is made based on activities over the last seven days. It has high internal consistency for the DSS (+0.89) but less for psychic distress (0.72), social desirability (0.76), energy level (0.71), ability to relax (0.69), and sleep (0.69) (Rosenthal, Roehrs, and Roth, 1993).
- **Stanford Sleepiness Scale (SSS).** The SSS is a seven point Likert scale that a person can use to assess how they are feeling at any time. An ideal score during the day is 1. Sleep debt is indicated if a person's score is 3 to7 during times when they should be alert. The scale was developed by Hoddes, Zarcone, Smythe, Phillips, and Dement (1973). It has not been sensitive to patients with sleep disorders (Herscovitch and Broughton, 1981) nor is it a valid measure of sleep propensity (Johns, 1993). The scale is below (Stanford Sleepiness Scale, n.d.).

Degree of Sleepiness	Scale Rating
Feeling active, vital, alert, or wide awake	1
Functioning at high levels, but not at peak; able to concentrate	2
Awake, but relaxed; responsive but not fully alert	3
Somewhat foggy, let down	4
Foggy; losing interest in remaining awake; slowed down	5
Sleepy, woozy, fighting sleep; prefer to lie down	6
No longer fighting sleep, sleep onset soon; having dream-like thoughts	7
Asleep	X

- **Toronto Sleepiness and Fatigue Scale (TSFS).** The TSFS has ten items and has been shown to have good internal consistency (0.84 sleepiness, 0.87 fatigue) (Shen et al., 2010).
- **Visual Analog Fatigue Scale (VAS-F).** The VAS-F is an 18 item scale. Developed by Monk (1989). It has two subscales: energy (5 items) and fatigue (13 items) (Lee, Hicks, and Ninomurcia, 1991). It has high internal consistency (+0.96) (Maxwell, 1978).
- **World Health Organization Quality Of Life Assessment Energy and Fatigue Subscale (EF-WHOQOL).** The EF-WHOQOL measures emotional exhaustion in burnout with four items. Saxena and Orley (1997) describe the collaborative approach taken to develop this measure. It included inputs from health care providers and receivers.

In addition to the self-rating of fatigue scales above, several measures are calculated from self-reported amount and quality of sleep as well as work schedule. These include the FAST (Hursh, 2003), the FAID (Dawson, 2002), and the Fatigue Index Tool (FIT) (Cebola, Kilner, 2009).

- The Fatigue Avoidance Scheduling Tool™ (FAST™) (Hursh, 2003)—FAST uses the SAFTE™ model which focuses on the influence of time of day and sleep/wake patterns on cognitive capacity and performance risks. It is used to anticipate worker fatigue, assist in scheduling to reduce errors, and improve safety, effectiveness, and quality of life. FAST™ is used by the U.S. Army, Air Force, Navy, and Marines, and also the FRA.
- The Fatigue Audit InterDyne™ (FAID™) (Dawson, 2002) - FAID™ calculates the work related fatigue for existing, or proposed work periods. The calculation is based on the time of day for the work and break periods, duration of work and break periods, previous work history, and biological limits on sleep recovery as set by the user. FAID™ is a well validated method of fatigue risk management when used with training and surveys. It is used by Transport Canada.
- The Fatigue Index Tool (FIT) (Cebola, Kilner, 2009)—FIT calculates a Fatigue Score from estimated sleep debt, the difference between actual number of hours slept and the optimum, quality of sleep, and time on shift. The score can account for napping, workload, and breaks. Program evaluation was performed at Air Navigation Service Provider (ANSP) by EUROCONTROL, FIT has not yet been used for any fatigue research or in any operational settings.

G.2 Objective Measures of Fatigue

Objective measures, such as reaction time, performance data, and physiological measures, rely on physical data that are obtained and substantiated by scientific means. The two most often used objective measures in sleep research are the MSLT in which a participant lies in a dark room to fall asleep. There are typically four or five 20 to 30 minutes sessions completed at two hour intervals. Sleep latency is defined as the time until the first epoch of sleep begins. The MWT is the second most often used objective measure. Opposite to the MSLT, a participant sits in a dark room and tries to remain awake for 20, 30, or 40 minutes.

Some commonly used objective measures of fatigue in ATC are the PVT and physiological measures (e.g., HR, heart rate variability (HRV), skin conductance level (SCL), EEG, ECG, blink rate, ocular movement, and body temperature). Objective measures are independent of rater biases and cannot typically be altered. However, while objective data are often preferable, they are also costly and certain items can be difficult to measure. In the case of physiological data, it is not always known what cognitive state or physical action has caused the physiological response. For example, instantaneous HR and HRV have both been associated with stress, fatigue, workload, and monotony (Collett, Averty, and Dittmar, 2009; Hill and Perkin, 1985; Rosekind et al., 1996a).

Two new objective measures that need further research are the Traffic Load Index (TLI) and the AWVT (Athènes et al., 2002; Tyagi et al., 2008). The TLI is a workload measure for ATC that is based on the situation being monitored, opposed to the participant’s perception of the situation.

The AWVT attempts to objectively measure mental fatigue with respect to the user's current cognitive abilities. Through measuring the user's working-memory, decision-making ability, and vigilance information may be gained concerning the individuals higher mental abilities at any given time. The scores derived from this test, the AFI, reflect mental fatigue level.

A summary of measures that have been used to measure air traffic controller fatigue is presented in Table G-1.

Table G-1. Advantages and Disadvantages of Air Traffic Controllers Fatigue Measures

Measure	Advantages	Disadvantages	Recommended Use
Auditory Working-memory Vigilance Task (AWVT) (Tyagi, Shen, Shao, and Li, 2008)	Objective measure for fatigue Track mental fatigue Unobtrusive Test- Re-test reliability	Further investigation required to test validity	Lab and Field Minimal training Quick and easy Objective measure
Fatigue Index Tool (FIT) (Cebola, Kilner, 2009)	Designed for ATC Asses fatigue causing factors Estimates sleep debt	Further investigation required to test validity Subjective measure	Lab and Field Minimal training Quick and easy Subjective measure
PVT (Lisper and Kjellberg, 1972; Powell, 1999)	Objective measure for fatigue Unobtrusive Test- Re-test reliability	Measures reaction time only Overly simplistic measure	Lab and Field Minimal training Quick and easy Objective measure
Blink rate (Morris and Miller, 1996)	Sensitive to mental fatigue Captures fluctuations in fatigue Little intrusion on task Continuous measure Not affected by participant/experimenter biases	Need environmental controls Not suitable for short tasks No direct relationship Potential for data artifacts Expensive	Lab and field High sensitivity Continuous measurement No interference with primary task In conjunction with subjective measures

Appendix H Performance Measures

This section includes measures of human performance, workload, situational awareness (SA), boredom, monotony, motivation, and stress.

H.1 Human Performance

A number of well recognized, industry standard performance measures for ATCs were used by CAASD researchers. Table H-1 below summarizes the performance measures used by ATC topic area and citation. Note, only completed CAASD studies with reported results are listed in Table H-1.

Table H-1. Air Traffic Controller Performance Measures

Topic	Citation	Performance Measures
Air Traffic Control Operational Error Analysis	Kinney, G. C., 1977, *The Human Element in Air Traffic Control: Observations and Analyses of the Performance of Controllers and Supervisors in Providing ATC Separation Services*, MITRE MTR7655, The MITRE Corporation, McLean, VA	OBJECTIVE • Operational errors
P-ATM	Bowen, K. C., S. H. Mills, D. J. Winokur, Nov 2007, *Results from Performance-Based Air Traffic Management En Route Human-in-the-Loop (HITL) Experiments*, MTR 070322, The MITRE Corporation, McLean, VA.	SUBJECTIVE • Workload (NASA Task Load Index (TLX); Air Traffic Workload Input Technique (ATWIT))
	Klein, K. A., Sept 2007, *Results of Performance-Based Air Traffic Management (ATM) Human-in-the-Loop Simulations - Large Terminal Radar Approach Control (TRACON) Environments*, MTR 070172, The MITRE Corporation, McLean, VA.	OBJECTIVE • Track length • Throughput • Inter-arrival time • Loss of separation • Time to detect pilot deviations from RNAV • Average transmissions to each plane • Average control transmissions to each plane SUBJECTIVE • Workload (NASA-TLX; ATWIT)
	Smith, E. C., Sept 2007, *Results of Performance-Based Air Traffic Management (ATM) Human-in-the-Loop Simulations - Situation Awareness in Future Terminal Radar Approach Control (TRACON) Environments*, MTR 070175, The MITRE Corporation, McLean, VA.	OBJECTIVE • Situation awareness (Situation Awareness Global Assessment Technique (SAGAT)) • Controller detection performance of pilot deviations

Topic	Citation	Performance Measures
		SUBJECTIVE • Workload (NASA-TLX)
	Smith, E., 2006, *Terminal Performance-Based Air Traffic Management (P-ATM) Validation Results*, MTR06W0113, The MITRE Corporation, McLean, VA.	SUBJECTIVE • Workload (NASA-TLX) OBJECTIVE • Loss of separation • Efficiency
	Winokur, D., K. Bowen, S. Mills, 2006, *En Route Human-in-the-Loop Experiment: Performance-Based Air Traffic Management (P-ATM) Operational Feasibility and Benefits Assessment*, MTR 06W0086, The MITRE Corporation, McLean, VA.	OBJECTIVE • Information content • Frequency congestion • Hearback/readback errors • Number of transmissions • Amount of repeated information SUBJECTIVE • Workload (ATWIT; NASA-TLX)
Surface Safety Logic	Sanchez, J., E. C. Smith, R. S. Chong, 2009, *Controller and Pilot Response Times to Runway Safety Alerts,* MITRE MTR090237, The MITRE Corporation, McLean, VA.	OBJECTIVE • Response time to safety alerts • Duration of response • Gaze patterns
	Sanchez, J., E. C. Smith, R. K. Stevens, July 2010, *Tower-Based Surface Safety System: Human Factors Analysis and Performance Validation Plan,* MITRE MTR100249, The MITRE Corporation, McLean, VA.	OBJECTIVE • Gaze patterns • Foveal fixations • Response times (Time of onset of communication transmissions and duration of transmissions among other simulator data were recorded for this measure)
Tower Approach Clearance Analysis	Estes, S. L., C. T. DeSenti, J. C. Kamienski, 2010, *Multiple Landing Clearances (MLC) Controller HITL* (Briefing), The MITRE Corporation, McLean, VA.	OBJECTIVE • Number of transmissions/minute • Plane's distance to runway threshold when the landing clearance was issued • Number of times controllers forgot to issue a landing clearance • Number of times controllers reissued landing clearances • Arrival/departure rate SUBJECTIVE • Controller estimates of plane's distance to runway threshold when

Topic	Citation	Performance Measures
		the landing clearance is issued (during current practice) • Controller descriptions of current multiple landing clearance practice • Controller opinions regarding the acceptability of the proposed caps

As indicated in Table C-1, the NASA Task Load Index (NASA-TLX) and the ATWIT were the most common subjective workload measures. Objective measures regarding controller performance included response times, OEs, and data on transmissions, as well as information regarding inter-arrival time, throughput, and arrival/departure rate. For performance and workload measures see Gawron (2008). This handbook contains descriptions, strengths and limitations, data requirements, thresholds, and references for sixty-seven performance, seventy-eight workload, and eleven SA measures. Also included is a section on pilot performance measures.

H.2 Workload

Workload is the non-automated tasks that an individual must manage and allocate mental resources towards. It is a multifaceted construct that is most frequently measured subjectively (by asking an individual how they are experiencing workload) or is inferred from what can be seen as being task load from the environment (Athènes et al., 2002). An individual experiences high workload when an excessive demand is placed upon their mental and physical resources (e.g., visual/auditory perception, memory, attention) (Wickens, 1984).

Workload in ATC has previously been measured based on subjective ratings that occur during or after a task. These are prone to rater errors due to individuals having to reflect on their perception of what the task was like. Task parameters that influence ATC workload are the number of aircraft under control, the duration or content of radio exchanges and phone conferences, and the complexity and time pressure of the traffic being managed (see for review Athènes et al., 2002; Stein, 1998). Athènes et al. (2002) have developed an objective workload measure for ATCs; the TLI. The TLI takes into account the number of aircraft being monitored, along with the gravity (uncertainty of conflict) and the urgency (time pressure) of the traffic. In preliminary studies, the TLI shows a strong correlation with activation of psychophysiological parameters when traffic load increased (Athènes et al., 2002).

In studies of the Performance-Based Air Traffic Management concept (P-ATM) researchers used a variety of metrics, including NASA-TLX and the ATWIT, to establish benefits provided by NextGen automation (Winokur, Bowen, and Mills 2006). The ATWIT technique is administered during the scenario enabling instantaneous ratings of workload. Using ATWIT, the researchers were able to establish the workload curve over the course of the scenario, identify where traffic levels were too high for the controller to maintain SA, and provide quantitative descriptions of workload benefits associated with the P-ATM concept.

Problems do not only occur during high workload, they also occur during low and moderate workload. During an investigation of operating irregularities, Schroeder (1982) revealed that most errors occurred during low or moderate workload periods. The probable causes of these errors were suggested to be problems with attention, judgment, and communication (Stager, Hameluck, and Jubis, 1989). During low or moderate workload, fatigue-ratings made in a diary study of ATC remained stable for up to four hours during low workload conditions (Spencer, Rogers, Birch, and Belyavin, 2000). Fatigue-ratings increased rapidly after two hours of sustained high workload (Spencer, Rogers, Birch, and Belyavin, 2000). The level of workload has been shown to influence OEs in all work situations; during high workload and after breaks (Della Rocco, Cruz, and Clemens, 1999), after traffic peaks (Hagemann, 2000), and during low or moderate workload (Stager, Hameluck, and Jubis 1989; Weikert and Johansson, 1999).

There is a considerable amount of research on workload. Both high and low workload seems to have a similar effect on the amount of fatigue an individual perceives. Despite this research base, few recommendations have been developed to alleviate the problem of workload. Identifying the proper solutions to workload issues would be a major step in alleviating workload fatigue. Table H-2 summarizes measures that have been used in research involving ATCs.

Table H-2. Workload Measures Used in Air Traffic Control Research

Measure	Advantages	Disadvantages	Recommended Use
NASA Task Load Index (NASA-TLX) (Hart and Staveland, 1988)	• Extensive use in Aviation • Widely validated • Reliable and sensitive	• Time consuming • No agreement on components of workload • Difficult to compare workload on different types of tasks	• Lab and Field • Multidimensional assessment • Low cost • Quick and Easy to use • Pen and Paper • Subjective assessment
Eurocontrol Recording and Graphical display On-line (ERGO) for Instantaneous Self Assessment (ISA) (Hering, Coatleven, 1996).	• Real-time measure • ISA is correlated with NASA-TLX	• May be intrusive • Limited 5-point rating scale	• Lab and field • Subjective assessment • Quick and easy
Air Traffic Workload Input Technique (ATWIT) (Stein, 1985)	• Developed for ATC • Records rating and how long it takes to make ratings • Does not breakdown workload by origin • Reliable and valid • Real-time measure	• Not multi-scaled or diagnostic	• Lab and Field • Low cost • Quick and Easy to use • Minimal training required • Low intrusion • Subjective assessment

Measure	Advantages	Disadvantages	Recommended Use
Assessing the Impact of Mental Workload (AIM) (Low, 2004)	• Mental workload by mental effort and task difficulty • Easy to implement in real-time	• Further investigation required to test validity	• Lab and Field • Multidimensional assessment • Quick and easy • Subjective assessment
Rating Scale Mental Effort (RSME) (Zijlstra and Van Doorn, 1985)	• Validated scale	• High level of variability • Overly simplistic measure	• Lab and Field • Low cost • Quick and easy • Low intrusion • Subjective assessment
Primary task performance	• Speed and accuracy of performance • Real-time environments • Nonintrusive	• Performance dependent on strategies • Measures may not indicate residual capacity	• Lengthy tasks • Direct index of performance • In conjunction with other measures • Easy to use
Secondary task performance	• Provide indication of residual resources • Pinpoint source of overload	• Dependent on selection of tasks • Low acceptance by operator possible	• Easy to use • Used with primary task performance measures
Traffic Load Index (TLI) (Athènes, Averty, Puechmorel, Delahaye, Collet, 2002)	• Real-time environment use • Objective and subjective data	• Use of a single expertise (Radar) • Time consuming to compute scores	• Lab and field • Objective and subjective • Requires substantial resources/training time
Performance and Usability Modeling (Kirwan et al., 1997)	• Sensitive to changes in events • Trace workload peaks • Multidimensional • Strong theoretical basis	• Validity questionable	• Lab and field • Multidimensional assessment • High diagnosticity • Substantial training required
Physiological measures (i.e., Collet, Averty, Dittmar, 2009)	• Sensitive to physical workload • Sensitive to high-level cognitive task demand • Captures fluctuations in workload • Little intrusion on task • Continuous measure • Not affected by participant/experimenter biases	• Need environmental controls • Not suitable for short tasks • No direct relationship between physiological response and workload • Potential for data artifacts • Expensive	• Lab and field • High sensitivity • Continuous measurement • No interference with primary task • In conjunction with subjective measures

In addition to the measures in Table C-2, workload models have also been developed and applied. Working memory load is used as a measure cognitive workload in the cognitiveControllerAgent (Estes, Bonaceto, Long, Mills, and Sogandares, 2009). The cognitiveControllerAgent, an autonomous model of human performance in the En Route domain, compares the number of chunks stored in working memory to known working memory thresholds for the purpose of estimating cognitive workload. The model also provides estimates of temporal workload (i.e., the amount of time needed to complete a given task). Temporal workload estimates provided by the model were, on average, found to be within 10% of En Route controller task times found in the literature.

Temporal workload, or time on task, has become a common measure of controller workload as it is often thought to represent the essence of controller workload (Couluris, Ratner, Petracek, Wong, Ketchel, 1974; Wickens, Mavor, and McGee, 1997). MITRE’s En Route Analysis (ERA) model provides an estimate of En Route controller time on task for every sector in the NAS in rolling 15 minute increments. That information is then used to calculate Position to Traffic (PTT) which is the number of staff necessary to handle the temporal workload imposed by the traffic level. Results of the ERA model have been found to provide estimates in line with staffing records kept by the FAA and is currently used in the processing of estimating yearly staffing needs (Boone and Lindsay, 2010).

System models have also found ways to integrate subjective workload ratings, like that of ATWIT, into their analysis toolset. The airspaceAnalyzer (aA), for example, was built to analyze sector complexity. aA acts an agent that manages traffic in much the same way a controller would. As part of the output of aA, the agent calculates the frequency and magnitude of various actions taken and translates them into a ATWIT score. The model was validated against En Route controller ATWIT scores and found to be to have a RMS error of less than 1 unit of the ATWIT result (ATWIT is a 1 to 7 score) (Stein, 1985).

In “Predicting Sector Capacity for TFM Decision Support”, Song, Wanke, and Greenbaum (2006) describes a different approach to modeling controller workload. Rather than measuring workload directly, their approach is to model two key drivers of workload: traffic volume and traffic complexity. Their approach uses clustering to identify flows within a sector. Sector capacity is defined by sector performance, which is a function of, among other things, excess miles flown in the sector. Future capacity can then be estimated through a process that uses pattern recognition to identify current conditions and likely conditions in the near future. In this way, their model provides an indirect estimate of controller workload in the form of a near term (on the order of hours) sector capacity estimate.

In addition to the subjective and model based measures of workload, human-in-the-loop (HITL) evaluations often collect data on correlates of increased workload. This includes the volume of radio transmissions, delay in accepting handoffs, early initiation of handoffs, traffic volume, traffic complexity, and the like. For example, in a study of the effect of a higher update rate on safety and En Route controller workload Kerns and Long (2010) used the number of heading instructions, vector size, time on vector, and delay until first vector as workload measures and found that, with the exception of one condition, these measures varied with perceived workload.

In another 2010 controller study of the impact of UAS on controller workload, the researchers found that the delay in accepting handoffs was, strongly correlated with subjective ratings of workload (Helleberg and Maroney, 2010).

There is a significant amount of work ongoing in the development of new measurement methods for workload in ATC. These new methods need further testing and validation. Once validation is acquired, it may be possible to combine workload measurements with fatigue measurements (physiological, ocular) to work towards developing a real-time fatigue measurement method. This task is only conceived in its infancy but with the correct focus could be further developed.

- Testing and validation of workload measurements in ATC.
- Identify factors and correlations between workload and fatigue.
- Identify high and low workload periods to implement changes to decrease OEs.

H.3 Situational Awareness

SA refers to the person's knowledge of task-related events at any given time. It requires an understanding of the current state of a system and assumes the ability to anticipate future changes. For ATC this means being aware of the overall condition of the airspace in which he/she operates, developing a mental picture of the aircraft position, flight plans, and weather conditions, as well as being able to detect the possibility and solve for future complications (see Figure H-1).

Figure H-1. Factors Affecting Situational Awareness Adapted from Jeannot, Kelly, and Thompson (2003)

Few of the articles included in the literature review on the effects of fatigue on ATCs cited SA. There are many studies and articles on SA, although most focus on measurement methods and validation of these measures. Few focus on ATCs. The articles that do focus on ATC do not draw a direct correlation between SA and fatigue. Research in ATC has found that failure to maintain SA often leads to errors after controller break periods or during low workload (Redding, 1992) and automation in ATC systems will also decrease an individual's SA (Endsley, 1999). These issues may be related to fatigue as it has also been implicated as the cause of performance decrements due to workload and OEs (Broach, 2005; Calvaresi-Barr, 2009). In a study that did assess SA (Smith, 2006; Smith, 2007), researchers deployed both Situation Awareness Global Assessment Technique (SAGAT) and a unique measure of human information processing alongside other measures of workload such as the time spent on the frequency by the controller. The information processing method demonstrated working memory loads in terminal controllers under conditions with and without the P-ATM tool.

Table H-3 summarizes the advantages and disadvantages of measures used to assess air traffic controller SA.

Table H-3. Measures Used to Assess Air Traffic Controller Situational Awareness

Measure	Advantages	Disadvantages	Recommended Use
Situation Awareness Global Assessment Technique (SAGAT) (Endsley and Rodgers, 1998)	• For ATC use • Direct face validity • Widely used • Objective data	• Based on simplistic model • Only suitable for stable environments • Expensive • Time consuming analysis • Interference with other measures	• Laboratory studies • Individual SA • Thorough analysis/assessment • Predefined SA elements • Standalone measure • Objective assessment
Situation Awareness Rating Technique (SART) (Taylor, 1990)	• Real-world task and simulation • No secondary task loading • Nonintrusive • No simulators needed • Team SA possible	• Reflect limited portion of SA • Poor validation scores • Questions overly generic • No post-trial data • Subjective data	• Lab and field • Individual and team SA • Global, subjective assessment • Quick and easy • Use in conjunction with other techniques
Situation Awareness for SHAPE Questionnaire SASHA L (real-time) and Q (post-trial) (Tsang and Vidulich, 1990)	• Developed for ATM • Generic and pointed questions	• Limited use/validity • Task simulation required • No Team SA	• Individual SA • Simulated environment • Generic and specific SA • Subjective assessment

Measure	Advantages	Disadvantages	Recommended Use
Situation Awareness in controllers on automation (SALSA) (Hauss and Eyferth, 2003)	• Cued recall • No post-trial data collection problems • Comprehensive SA assessment • Recognizes elements of environment changes	• Weighted procedure occurs after simulation • Queries may overload • Requires simulators • Interference with other measurements	• Laboratory study • Standalone measure • Quick and easy assessment
Situation Present Assessment Method (SPAM) (Durso et al., 1999)	• High validity • Distinguishes workload from SA • Low intrusion • Quick/easy • Objective measure	• Low construct validity • Limited use • Long proportion time • Difficult in multi-sector simulations • Query directs attention to information	• Laboratory study • Quick/Easy • Training time required
Situation Awareness Verification and Analysis Tool (SAVANT) (Willems and Heiney, 2002)	• ATM support • Queries relational information • No post-trial problems	• Disruptive to task • Long preparation time	• Laboratory study • Alternative to SAGAT and SPAM
Eye Tracker	• Unobtrusive • Objective measure • Team SA	• Indirect assessment of SA • Difficult equipment • Time consuming data analysis	• Lab and Field • Measurement sensitivity • Individual and Team SA

SA and fatigue in ATC has a very small research base. The major topics in SA research are focused on measurement methods, interviews, and OEs. Research is needed to determine the exact conditions causing a failure in SA.

- Are these failures in SA caused by fatigue?
- What exactly is happening to cause lapses in SA?
- What methods can be practiced to reduce these lapses?

H.4 Boredom and Monotony

Monotony is a mental state that develops slowly due to reduced activation that may occur during long, uniform, and/or repetitive tasks which may lead to a decrease or fluctuation in performance, drowsiness, and/or tiredness (Straussberger, 2006). A monotonous situation is one that remains unchanged or changes only in a predictable way. The state of monotony is the stimulus situation experienced by an individual as fatigue and/or satiation (McBain, 1970). Monotony can be distinguished as uneventful or repetitive (Johansson, 1989). Uneventful monotony is comparable to a control-room operator’s monitoring, while repetitive monotony is comparable to that of an assembly worker. Monotony and repetitiveness should be distinguished from boredom (Baldamus, 1951). Boredom arises when the individual is required to work at a repetitive task beyond the point where they would normally want to quit the task (Scerbo, 2001). Boredom consists of a cognitive component of the perception assigned to the task characteristics and an affective component assigning interpreting the perception (Hill and Perkins, 1985). When individuals perceive a task as homogeneous and/or undifferentiated, they perceive the task as monotonous or boring, and affectively consider the task as frustrating. Boredom may also be accompanied by an increase in HRV, see Figure H-2 (Hill and Perkin, 1985).

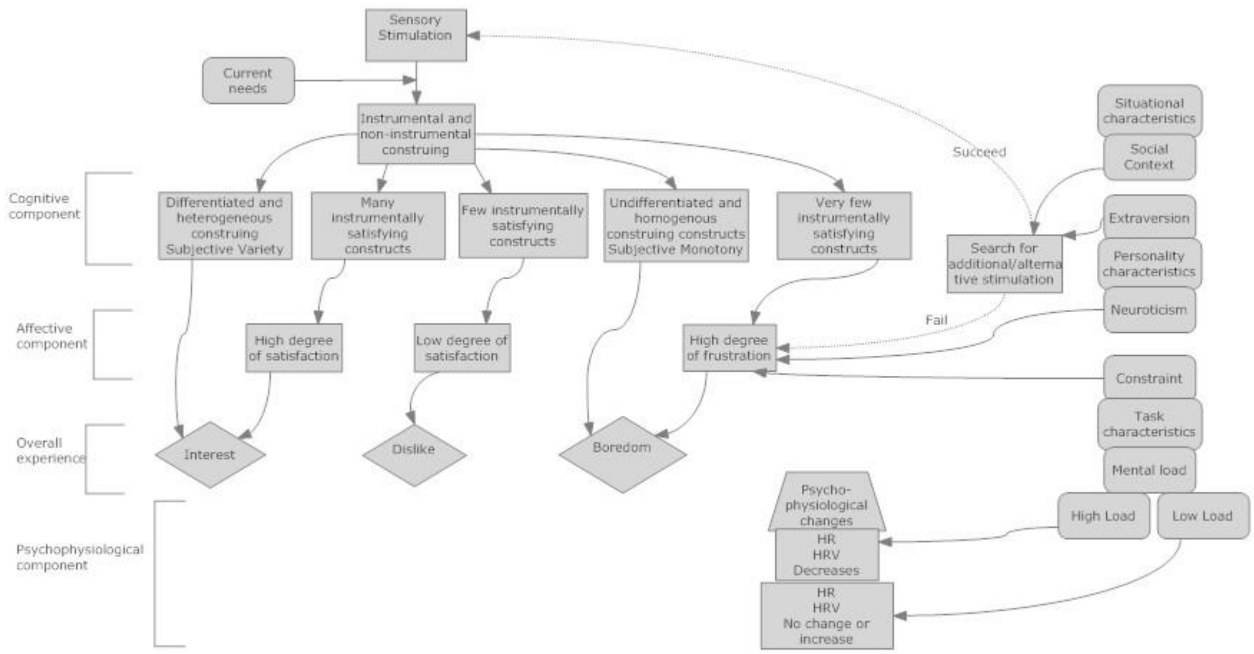

Figure H-2. Effects of Boredom Adapted from Hill and Perkin (1985)

Past research suggests differences between monotony and boredom as compared to fatigue (Barmack, 1939; Geréb, 1978). Barmack (1939) suggests that the evidence for this difference was that participants would rate a monotonous task as predominantly boring, not fatiguing. However, this is a matter of semantics and each participant may have differing views of what is boring or fatiguing. Frishman's (1990) findings were that both monotony and fatigue would reduce an individual's ability to discriminate difference in a 60-minute signal detection task. Participants experiencing a state of monotony had a greater number of false alarms than those experiencing fatigue.

Satiation occurs when an individual is stuck performing a task that they are obligated to perform and experiences feelings of agitation or annoyance (Berman, 1939; Ryan, 1947; Straussberger, 2006). Satiation is predominantly dependent on the individual's perception and attitudes towards the task and often occurs when there is low incentives or if the person is unable to meet the task demands (Richter and Hacker, 1998).

In ATC monotony can occur in all traffic situations. A monotonous traffic situation occurs when the traffic characteristics are dominated by traffic that displays little variation, requires minimal action from the controller, and the controller does not feel challenged by the task (Thackray, Bailey, and Touchstone, 1977). Monitoring situations that require sustained attention, such as low traffic situations that require few actions (e.g., night shift) may lead to uneventful monotony (Schroeder, Touchstone, Stern, Stoliarov, and Thackray, 1994).

Areas to look for monotony include runway allocation for approach and departure routes, sector forms, routine air traffic, and parallel. Also, the distribution of actions, such as controlling and monitoring, may develop monotony. Multiple factors may affect the level of monotony experienced. Individual characteristics such as age, experience or training, job satisfaction, motivation, psychological and physiological state, and personality traits may include a disposition towards boredom or preferences in working styles (e.g., extraversion, conscientiousness). Environmental factors may also play a part in monotony; such as the work environment (e.g., room temperature) or organizational factors (e.g., work schedules).

Past research on monotony has limited transfer opportunity to ATC. Previous studies have focused on driving simulators, assembly line work, and maintaining vigilance. Maintaining vigilance is one of the many components of ATC performance and has been studied frequently (Straussberger, 2006). Workload studies suggest that a higher level of incident risk occurs during low/moderate traffic density (Weikert and Johansson, 1999). Oftentimes, low/moderate traffic density occurs during night shifts and can be monotonous. Also, sectors and traffic flows have the tendency to be repetitive. Unfortunately, most incident reporting systems do not gather information concerning individual controller factors that may help to identify the cause of incident occurrences. As of yet, there is no model to help identify errors under low traffic load.

Straussberger (2006) performed multiple laboratory and field studies to operationalize monotony in ATC, determine which factors were evoked and how they could be measured, and suggested countermeasures that could reduce the potential of monotony. This review goes into great detail on their experimental design and offers the chance for other researchers to access the data and perform further analysis. From this research a model of monotony in ATC was developed to identify the factors contributing to monotony, the physiological and behavioral states, and the subjective experience (see Figure H-3).

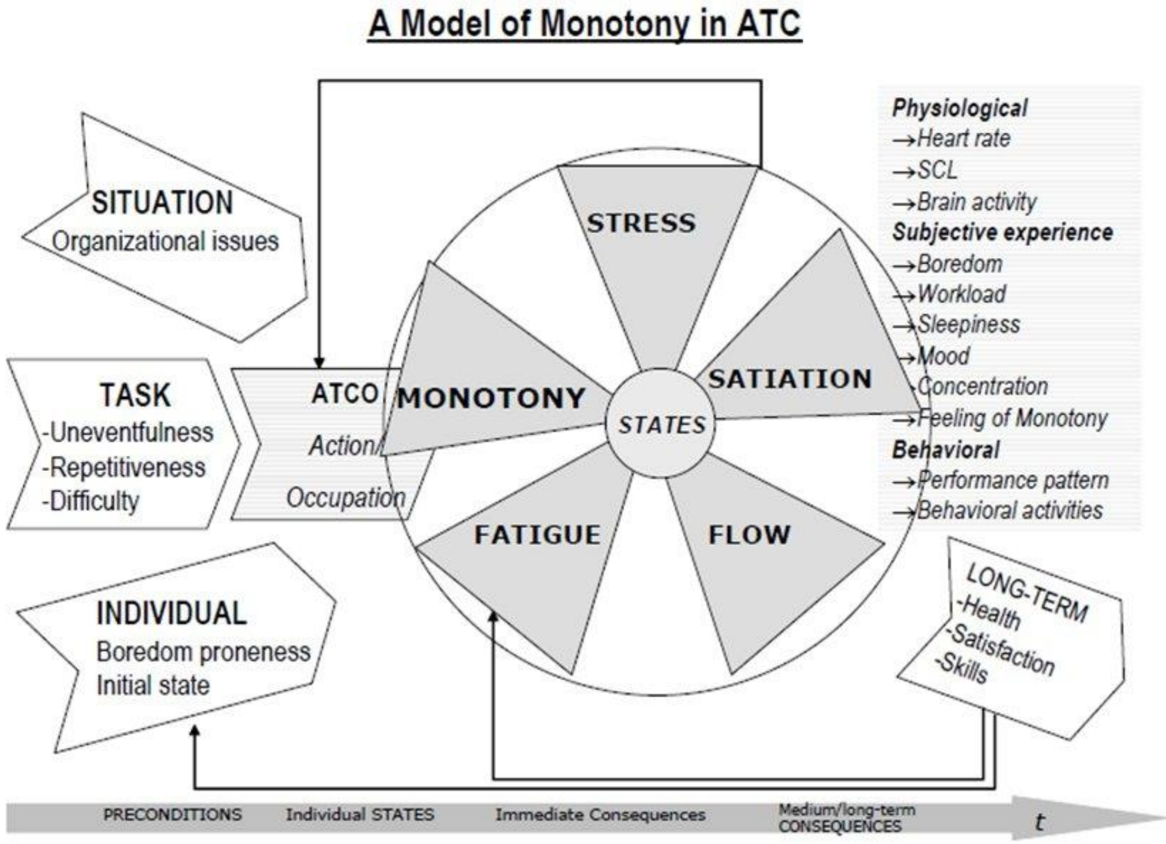

Figure H-3. A Model of Monotony in ATC from Straussberger (2006)

Measures of boredom, vigilance, and monotony used in ATC fatigue research are summarized in Table H-4.

Table H-4. Measures of Boredom and Monotony Used in Air Traffic Controller Fatigue Research

Measure	Advantages	Disadvantages	Recommended Use
Inverted Heart Rate (Straussberger and Schaefer, 2007)	• Multidimensional • Cognitive tasks • No overt responses • Continuous recording • Objective measure	• Artifacts possible • Expensive	• Lab and field • High sensitivity • No task interference • Training required • In conjunction with subjective measures
Aircraft deviations noticed (Stedmon et al., 2007)	• Not affected by biases • High face validity • Easy data collection • Nonintrusive • No training required	• May effect subjective measures • Dependent on strategies used • Dependent on workload	• Lab and field • Objective assessment • Easy to use • No training
Subjective Sleepiness and feeling of monotony (Straussberger and Schaefer, 2007)	• High face validity • Unobtrusive • Inexpensive and easy	• Inter-subject variability • Subject to bias, preconceptions, and memory limitations	• Lab and field • Low cost • Quick and easy • During and post-task • Unobtrusive
Dundee Stress State Questionnaire DSSQ (Hitchcock et al., 2003)	• Well validated • Transient states (mood, arousal, fatigue)	• Inter-subject variability • Subject to biases, preconceptions, memory limitations	• Lab and field • Low cost • Quick and easy • Unobtrusive
Standard Shiftwork Index (SSI) (Costa et al., 1995)	• High face validity • Unobtrusive • Inexpensive • Easy data collection	• High level inter-subject variability • Subject to biases, preconception, memory limitations	• Lab and field • Low cost • Quick and easy • Unobtrusive

The topic of monotony has a decent starting point of research. Measurement methods have been identified and may require further validation. Further research should be performed to validate these methods and to help evaluate the situations that are causing monotony.

- Is monotony arising from automation?
- What changes can be made to reduce monotony and improve alertness on task.
- Are certain individuals more susceptible to monotony?
- What roles do other states (fatigue, stress) play on monotony

H.5 Motivation and Stress

Table H-5 summarizes measures that have been used to assess air traffic controller motivation and stress.

Table H-5. Measures Used to Assess Air Traffic Controller Motivation and Stress

Measure	Advantages	Disadvantages	Recommended Use
Scale of feelings (Straussberger, 2006)	• Inexpensive • Easy data collection	• Multicollinearity between stress, monotony, fatigue, and satiation • Requires work periods over 4 hrs.	• Extended work periods • Quick and easy
Copenhagen Psychosocial Questionnaire (Arvidsson et al., 2006)	• Dimensions of stress distinguished • High face validity • Unobtrusive • Inexpensive	• High inter-subject variability • Subject to biases, preconceptions, or memory limitations	• Multidimensional measurement • Low cost • Quick and easy • Unobtrusive
Stress Diagnostic Survey (Lesiuk, 2008)	• Perceptions of stress • High face validity • Unobtrusive • Inexpensive and easy	• High level of inter-subject variability • Subject to biases, preconception, memory limitations	• Multidimensional measurement • Low cost • Quick and easy • Unobtrusive
Systolic and diastolic blood pressure/cortisol/HR/HRV	• Objective measure • Multidimensional • Suited for cognitive tasks • Continuous recording	• Artifacts present • Expensive • Requires expertise for data collection	• Lab and field • High sensitivity • Continuous measurement • Does not interfere with primary task • With subjective measures
Human Computer Trust Rating Scale (Kauppinen, Brain, and Moore, 2002)	• Trust measure • Valid and Reliable	• Subject to biases, preconception, memory limitations	• Lab and field • Low cost • Quick and easy • During or post-task • Multidimensional
SHAPE Automation Trust Index (SATI) (Goillau et al., 2003)	• Trust in ATC automation • Easy to administer	• Trust as binary questionable • Subject to biases, preconception, memory limitations	• Lab and field • Low cost • Quick and easy • During or post-task

MITRE experience in human factors and human performance evaluation can be traced back to 1977 when FAA requested MITRE assess FAA data and reports on OEs occurring within ATC operations, determine where and why the errors were occurring, and recommend actions to resolve identified problem areas. While MITRE's early human factors/human performance experience was limited to the analysis of rather primitive ATC OE data and observations made during site visits to active ATC facilities, more recent experience has involved sophisticated evaluations of not only new, complex concepts of ATM (e.g., P-ATM), but of the acceptability of the human-in-the-loop interfaces between ATCs and P-ATM. Such HITL experiments have resulted in changes in P-ATM to make it more user-friendly, efficient, and productive.

Further, at FAA request, MITRE has developed technically advanced, high-fidelity prototype training systems (enrouteTrainer and Terminal Trainer). In the true spirit of HITL system evaluation, these training systems prototypes are being evaluated for feasibility and usability in real-world ATC environments as used by real-world ATCs. Table C-6 below presents citations of MITRE Human Factors, Human Performance and HITL research, studies, evaluations, and analyses which are reviewed in the following sections and from which lessons learned were drawn. The following sections offer synopses of the studies, evaluations and experiments cited in Table H-6.

Table H-6. Relevant CAASD Research

Topic	Citation
Air Traffic Control Operational Error Analysis	Kinney, G. C., 1977, *The Human Element in Air Traffic Control: Observations and Analyses of the Performance of Controllers and Supervisors in Providing ATC Separation Services*, MITRE MTR7655, The MITRE Corporation, McLean, VA
En Route Trainer	Weiland, M. Z., 2006, *Rapidly Deployable Stand Alone Air Traffic Control Trainer (R-SAT) Laboratory Evaluation*, MTR 06W000040, The MITRE Corporation, McLean, VA
	Weiland, M. Z., A. Worden, Dec 2006, *Preliminary Evaluations and Benefits Report from Field Evaluations at ZID*, MTR 060182, The MITRE Corporation, McLean, VA.
	Worden, A., Dec 2007, *The enrouteTrainer Evaluation and Benefits Report from Field Evaluations at Indianapolis ARTCC*, MTR 07W0000364, The MITRE Corporation, McLean, VA.
P-ATM	Bowen, K. C., S. H. Mills, D. J. Winokur, Nov 2007, *Results from Performance-Based Air Traffic Management En Route Human-in-the-Loop (HITL) Experiments*, MTR 070322, The MITRE Corporation, McLean, VA.
	Couluris, G. J. et al., 1974, Capacity and Productivity Implications of Air Traffic Control Automation, Federal Aviation Administration, Systems Research and Development Service, FAA-RD-74-196, Washington D.C.
	Estes, S. L., C. Bonaceto, K. Long, S. Mills, F. Sogandares, 2009, Carbon Copy: The Benefits of Autonomous Cognitive Models of Air Traffic Controllers in Large-Scale Simulations, In *Proceedings of the USA/EUROPE Air Traffic Management R&D Seminar*, Napa, CA.
	Boone, D., K. Lindsay, 2010 *Overview of MITRE's En Route Analysis Capabilities*, MITRE F065-B10-007, The MITRE Corporation, McLean, VA.
	McMillan, E., Sept 2006, *A Framework for Productivity Improvement Validation for*

Topic	Citation
	Performance-Based Air Traffic Management (P-ATM) Concept, MITRE Product MP 060192, The MITRE Corporation, McLean, VA.
	Klein, K. A., Sept 2007, *Results of Performance-Based Air Traffic Management (ATM) Human-in-the-Loop Simulations - Large Terminal Radar Approach Control (TRACON) Environments*, MTR 070172, The MITRE Corporation, McLean, VA.
	Smith, E. C., Sept 2007, *Results of Performance-Based Air Traffic Management (ATM) Human-in-the-Loop Simulations - Situation Awareness in Future Terminal Radar Approach Control (TRACON) Environments*, MTR 070175, The MITRE Corporation, McLean, VA.
	Smith, E., 2006, *Terminal Performance-Based Air Traffic Management (P-ATM) Validation Results*, MTR06W0113, The MITRE Corporation, McLean, VA.
	Wickens, C. D., A. S. Mavor, J. P. McGee, 1997, *Flight to the Future: Human Factors in Air Traffic Control, Panel on Human Factors in Air Traffic Control Automation*, National Research Council, National Academy Press, Washington, D.C.
	Winokur, D., K. Bowen, S. Mills, 2006, *En Route Human-in-the-Loop Experiment: Performance-Based Air Traffic Management (P-ATM) Operational Feasibility and Benefits Assessment*, MTR 06W0086, The MITRE Corporation, McLean, VA.
Surface Safety Logic	Sanchez, J., E. C. Smith, R. S. Chong, 2009, *Controller and Pilot Response Times to Runway Safety Alerts*, MITRE MTR090237, The MITRE Corporation, McLean, VA.
	Sanchez, J., E. C. Smith, R. K. Stevens, July 2010, *Tower-Based Surface Safety System: Human Factors Analysis and Performance Validation Plan*, MITRE MTR100249, The MITRE Corporation, McLean, VA.
Terminal Training	Vu, J. M., M. Z. Weiland, Feb 2009, *Terminal Trainer Prototype Field Evaluation Report*, MTR 090055, The MITRE Corporation, McLean, VA.
	Weiland, M. Z., April 2010, *Terminal Trainer Prototype Initial Field Evaluation Plan for Potomac TRACON*, MTR100122, The MITRE Corporation, McLean, VA.
Tower Approach Clearance Analysis	Cheng, J., V. D. Nene, P. Diffenderfer, May 2010, A Functional Analysis of Staffed NextGEN Tower (SNT) Operations, MP090222R1, The MITRE Corporation, McLean, VA.
	Estes, S. L., C. T. DeSenti, J. C. Kamienski, 2010, *Multiple Landing Clearances (MLC) Controller HITL* (Briefing), The MITRE Corporation, McLean, VA.

Air Traffic Control Operational Error Analysis

Background. One of MITRE's first documented forays into human performance measurement dates to 1976/77. The cited paper was written in response to an FAA Air Traffic Service (ATS) request for an analysis of the performance of the human element, particularly controllers and first-line supervisors, specifically with regard to its program for reporting and investigating system errors (a system error being defined at the time as a penetration of the "buffer zone" around a controlled aircraft where the dimensions of the zone are minimum standards for horizontal and vertical separation distances (in current parlance, a "loss of separation").

ATC Operational Error Analysis. Although such OE penetrations were a relatively rare event in ATC system operations and involved a small portion of the operational work force in any given year, their occurrence indicated to FAA that operational goals had not been met. Since previous work had shown that over ninety percent of the system errors that were reported were attributed directly to failure of the human element in the ATC system, MITRE's research focused mostly on the performance of controllers and first-line supervisors (Kinney, 1977).

MITRE's investigation consisted of three related parts: 1) the analysis of data in the FAA's computerized data base for system errors, 2) the study of system error case histories, and 3) visits to centers and terminals for on-site observation and analysis. MITRE's analysis of the FAA database and of system error case history was extensive, providing FAA with in-depth insight into the distribution of OE elements and the error's underlying factors among controllers, supervisors, persons, facilities and workloads. MITRE visits to facilities lasted from 9 to 10 days for three of the ARTCCs, and for 2 days at Minneapolis Center. The Minneapolis visit concentrated on practices and problems of first-line supervision. The visits to terminals lasted 5 days. In all, a total of 8 facilities were visited and 300 operating position observations were completed. MITRE's report concluded with twelve recommendations for the FAA ATS to consider to improve not only controller error rates, but to improve front-line supervisor performance, and its error reporting and analysis processes. These recommendations are presented in Table H-7 (Kinney, 1977).

Table H-7. Recommendations from ATC Operational Error Analysis[8]

Actions for Controllers	
Controller Awareness	It is recommended that controller awareness and competence in these matters be increased by including in their training curricula a course in the .basic capabilities and limitations of controller performance in the ATC system. Such a course should include fundamentals of learning, forgetting, memory functions, habit formation, behavior modification, self-discipline, practice methods, vision, hearing, sensory capacities, stress, fatigue, alcohol and drugs, attitude formation and control, social interaction, mechanisms of adjustment, and principles of safe practice.
Control Techniques and Work Habits	It is recommended that good operating practices for all operational positions in the ATC system be documented in a national procedures document (7110 Series) by listing and describing the associated control techniques and positional work habits to the required level of detail, added to classroom and simulation training at the FAA Academy, added to the contents of On the Job (OJT) Instructor Courses and facility simulation training, included in proficiency evaluation checklists, and included as reportable items in system error GO Team records, Review Board reports, and in other national files and data bases.

[8] Adapted from Kinney, 1977

Actions for Controllers	
Environmental Interference	For the following influences observed or otherwise identified, it is recommended that non-work related activities such as conversations, movements, and other auditory and visual stimulation be prohibited in radar rooms, control cabs, and other operational work areas, except as explicitly approved by supervision in accordance with facility documentation, personnel not on duty or not on position be present in operational work areas only upon explicit supervisory approval, including visitors whose conduct shall be monitored and controlled by supervision, and work-related activities such as direct voice communications and personnel movements be confined to those made explicit in improved facility documentation, and be conducted in a manner so as not to constitute distractions for operating personnel.
Operational Supervision	It is recommended that operational supervision by an administratively appointed, responsible, and accountable person or persons, usually a first-line supervisor, or temporary supervisor, be present and functioning in the operational supervisory role at all times except as explicitly specified in improved facility-documentation. To provide the recommended operational coverage, it will be necessary at some facilities to increase the size of the supervisory body by appointing additional Team Supervisors. Present staffing does not allow enough Team Supervisors to perform the recommended operational supervisory tasks while other Team Supervisors are engaged in currency training and other required tasks.
Actions for First-Line Supervisors	
Supervisor Awareness	It is recommended that the awareness and competence of first-line-supervisors and of any person performing as a first-line supervisor (usually a Team Supervisor or equivalent) be increased by including in their training curricula additional materials in the FAA Management Training School to· cover topics including teaching and instructional methods, group dynamics, attitude formation, behavior modification, supervisory techniques, performance monitoring, and applied psychology of leadership.
Details of Good Operating Practices	Similarly for supervisors it is recommended that the job description and Position Performance Standards for Team Supervisors be reconstructed to include the topics and tasks of operational supervision including a list of performance standards for controllers, a description of the required supervisory role, and references to prerequisites in training topics and skill levels.
Training of first-Line Supervisors	It is recommended that .all persons required to perform as operational supervisors be given formal training at required tasks and task areas (in addition to those already cited) to qualify for operational duty including currency training in positional operating tasks, application of supervisory techniques, positional manning procedures and practices, on-the-job deportment of operational personnel, Civil Service Commission rules, regulations, policies, and procedures as they apply to the operational positions, personnel, and situations of concern, procedures and schedules for all required reporting forms and administrative documents, FAA medical and personnel services and their utility, contents and application of the union contract, principles of safe practice in air transportation, and specific aspects of public speaking, group addressing, and writing tailored to the Team Supervisor's job requirements.
Data on Controller Performance	It is recommended that hardware and software capabilities be implemented to provide supervisors with current data on the quantity and quality of controller performance of required, un-required, and undesired operational activities, and these data and additional information be employed in routine and periodic proficiency evaluations for operating controllers.

Actions for Controllers	
System Error Detection, Investigation and Reporting	
Report forms	It is recommended that FAA Order 8020.3A be revised to provide for reporting data and information on system error elements and underlying factors including practices of the personnel involved, data and information on the performance of the documented control techniques and work habits discussed and recommended above, data and information on the activities and events listed in Section 4.7.3 above, including normative data, improved testimony from witnesses and involved personnel, measures taken to ensure the integrity of data and information in the report, reasons for not reporting items or otherwise failing to comply with reporting procedures, and a description of the reasons why the system error was detected and reported.
Directives and Guidance	To meet the above recommended actions, it is further recommended that the revised FAA Order 8020.3A (and supplements and other documents related to it) provide direction and guidance including a glossary of terms and their definitions as used in or required by the order, a new set of causal categories with the rules for selecting a category from the data in the revised report forms, guidelines and rules for the time period to be covered by the report, rules and guidelines on the data and information to be collected and reported, especially on correlations among events and their times of occurrence, categories of system errors related to seriousness, hazard, and other. important aspects of the system error and the related human performance, and rules for placing each system error being reported into these categories, categories of reporting procedures related to the categories and tailored to the need for detail, authentication of reported materials, time and effort to be expended, and verification of information, and provisions for supporting staff including standards for qualifying personnel as board members and supporting staff.
Dissemination of System Error Data	It is recommended that a program be implemented for constructing a means of collecting and disseminating testimony from involved personnel on their acts which provides key information with anonymity of the source, the information to be on the system error elements and their underlying factors which led to the system error, collecting, collating, summarizing, and evaluating system error data and preparing a document for use in the ATC community, distributing the document on a frequent and timely basis, soliciting responses on the use and usefulness of the document in the field, and modifying and improving the document and system error reporting program as needed.

CAASD En Route Trainer HITL/Human Performance Evaluation Experiments

Background. Attrition scenarios developed by the Department of Transportation show that 70% of the controller workforce will be eligible to retire by 2011. As such, thousands of ATCSs are expected to exercise eligibilities and retire from the FAA workforce over the next year or two. This situation has required the FAA to hire and train many new controllers in a short period of time. At the same time, the FAA expects air traffic volume and complexity to continue to increase for the foreseeable future and with it, the demand for ATC services. In addition to the FAA's training needs for newly hired controllers, it is also recognized that existing training processes and technologies are not adequate to support ongoing training for the existing workforce of CPCs as En Route systems evolve.

CAASD and the FAA have been conducting research over the past several years to determine where improvements and changes need to be made in the ATC training process. One of the proposed changes put forth by CAASD is the deployment of a training system that includes an improved curriculum and employs a high fidelity simulation system with voice recognition and speech synthesis capabilities, as well as Intelligent Tutoring System (ITS) technology. To evaluate these proposed capabilities, measure the benefits of their implementation, and reduce the risk associated with their acquisition, CAASD has developed a high-fidelity training simulator prototype called the enrouteTrainer. The enrouteTrainer is designed to present high-fidelity training scenarios that simulate real-world ATC situations.

The following paragraphs synopsize the experimental design and analytical techniques employed during En Route Trainer evaluation efforts as representative of CAASD human performance measurement and analysis capabilities; specific experiment results reported in the cited references will not be repeated here.

Rapidly Deployable Stand Alone Air Traffic Control Trainer (R-SAT) Laboratory Evaluation. To assess the CAASD-developed Rapidly-Deployable Stand-Alone ATC Trainer (R-SAT) prototype's readiness for its first field trial, a two-phased laboratory evaluation was conducted at CAASD. The laboratory evaluation was conducted in two phases. The first phase of the evaluation was conducted to establish the overall feasibility and technical capabilities of R-SAT to accomplish facility training at an FAA field ATC facility. The second phase of the evaluation was conducted to enable a more in-depth and comprehensive analysis of R-SAT's capabilities within the context of Stage IV facility training objectives (Weiland, 2006).

The first laboratory evaluation was conducted over the course of two days. R-SAT was primarily operated by CAASD ATC subject-matter experts and observed by participants, who consisted of En Route ATC training subject matter experts, and other FAA personnel. R-SAT was operated using three scenarios for the Terre Haute (HUF) sector of Area 4. The scenarios showed the ability of R-SAT to present recorded traffic as well as run pre-existing Dynamic Simulator (DYSIM) scenarios from ZID (Weiland, 2006).

The second phase of the evaluation was conducted over a period of three days in the CAASD laboratory at MITRE. The FAA field site ARTCC Training Manager and two members of his training staff participated by observing and operating R-SAT running various scenarios. The set of scenarios for this phase was more comprehensive than the scenarios used in the first evaluation and included examples of each of the operational uses (i.e. review, skill, and full length scenarios) for Terre Haute and Rushville sectors from Area 4 (Weiland, 2006).

Evaluation data for these issues was collected in two ways during the evaluation. First, the operation of R-SAT was observed by the participants and detailed notes of the comments made and issues raised during observation were recorded. In addition, evaluation issues were formulated into a specific set of operational questions that were discussed following each phase of the laboratory evaluations. In general, participants were positive about R-SAT's ability to deliver training if their recommendations for its improvement were incorporated into the next version of R-SAT. These recommendations included changes to the ATC simulation, R-side and D-side Computer Human Interface (CHI), and the Auto Sim-Pilot voice system (Weiland, 2006).

Preliminary Evaluations and Benefits Report from Field Evaluations at ZID (Phase I). The specific purpose of this field evaluation was to assess the operational usability, acceptability, and benefits of the enrouteTrainer (previously referred to as the R-SAT) through its use during Stage IV facility training. During its initial field trial, the enrouteTrainer was used during Stage IV training to provide ATCs with Skill Training (concentrating on specific ATC skills while minimizing emphasis on other skills), Full Length Training (realistic ATC training using hour-long interactive scenarios), and Live Traffic Review (which allows "developmental" (student) to watch scenario events without interacting with the system). Specific expected benefits being assessed during this field evaluation included (Weiland, Worden, 2006):

- Reduction in training hours required to prepare for On-the-Job-Training (OJT).
- Reduction in the number of support staff required to accomplish training.
- Reduction in overall calendar time needed for training developmental.

To achieve the anticipated benefits of enrouteTrainer, four key differences between Traditional DYSIM Stage IV Radar Simulation Training and enrouteTrainer Stage IV training were identified and incorporated (Weiland, Worden, 2006).:

- A portion of the traditional DYSIM scenarios were delivered on the enrouteTrainer platform.
- Each developmental ran 54 simulation scenarios instead of 40 simulation scenarios in a condensed time schedule, so developmentals were able to have more simulation time per day of training than they would have using DYSIM alone.
- Skill scenarios were used at the start of simulation training instead of the traditional DYSIM familiarization scenarios.
- Calendar time was reduced from six weeks to five weeks. This time reduction was achieved through a detailed and balanced daily schedule which was possible by taking advantage of the flexibility afforded by the enrouteTrainer.

To measure whether the expected benefits were realized, data were collected throughout the trial. The data collected consisted of qualitative as well as subjective measures and included (Weiland, Worden, 2006):

- Training times (number of hours of simulation training for each developmental, and calendar training time for Simulation Phase training for each developmental).
- Evaluation Questionnaires (after skill training, after completion of 18 instructional scenarios and two Evaluation scenarios and after completion of the additional familiarization scenarios).
- Observation (direct observation of instructors working with developmental during enrouteTrainer sessions).

Based on collected feedback and evaluations, it was clear that the field trial was yielding positive results. Both instructors and students were impressed by enrouteTrainer capabilities and the benefits of using the system for Stage IV facility training (Weiland, Worden, 2006).

The enrouteTrainer Evaluation and Benefits Report from Field Evaluations at Indianapolis ARTCC (Phase II). The purpose of this field trial was to continue the assessment of the enrouteTrainer and its benefits for the delivery of training that was begun in 2006 and reported in Monica Z. Weiland and Aileen Worden (2006). *Preliminary Evaluations and Benefits Report from Field Evaluations at ZID*. This second field evaluation of the enrouteTrainer at the ZID ARTCC was conducted during the radar simulation component of Stage IV training for two Area 5 air traffic controller developmentals. Although the enrouteTrainer platform used in the evaluation was the same as that used during the preliminary evaluation and the evaluation's primary objectives remained the same, the list of expected benefits changed somewhat (Worden, 2007):

- Better student preparation for OJT.
- Effectiveness of training was expected to be facilitated by the pause and playback features.
- More efficient student throughput because the enrouteTrainer enabled two students to train on the same scenario simultaneously, a functionality not currently available with the currently used DYSIM system.
- Voice recognition and synthesis capabilities were expected to reduce the human resource costs associated with the scheduling and use of human sim-pilots.

To achieve the anticipated benefits of enrouteTrainer, the three key differences between Traditional DYSIM Stage IV Radar Simulation Training and enrouteTrainer Stage IV training were revised over those identified and incorporated in the preliminary evaluation and are now listed as (Worden, 2007):

- The ten 60-minute traditional DYSIM FAM scenarios were replaced by twenty-four 30-minute enrouteTrainer SKILL scenarios.
- The remaining DYSIM scenarios (Instructional (INSTR), Evaluation (EVAL) and Additional Familiarization (ADD FAM)) were converted to run on the enrouteTrainer platform.
- Calendar time was further reduced, from 4 weeks to 3.5 weeks. This time reduction was achieved through a detailed and balanced daily schedule which was possible by taking advantage of the flexibility afforded by enrouteTrainer.

Otherwise, the design, preparation, conduct, data collection and analysis for this evaluation was the same as those used in the preliminary evaluation synopsized above. Overall, this enrouteTrainer field trial was assessed as a success. This trial was the first time the enrouteTrainer was used to deliver all of the radar simulation training as the prototype was deemed sufficient to support all aspects of ATC radar simulation instruction. The instructors felt strongly that the students benefitted from the high-fidelity simulation as well as the quality and content of the enrouteTrainer scenarios and training experience and the expected curriculum time-saving benefits were realized as well (Worden, 2007).

CAASD P-ATM HITL/Human Performance Evaluation Experiments

Background. Traffic growth predicted for the NAS dictates that a new concept for air traffic operations must allow for more traffic to be handled than currently possible by increasing controller productivity without sacrificing efficiency and safety. To manage this increasing demand and assure continued safe and efficient operations within the NAS, the FAA asked CAASD to develop and validate a mid-term concept for the NAS to accommodate the increasing traffic demand while increasing controller productivity. In response, CAASD developed the P-ATM concept of operations as well as an on-going HITL evaluation process to validate productivity improvement for the P-ATM concept of operations. Validation efforts began in 2006 and validation results are described in the cited references, below. The following paragraphs synopsize the experimental design and analytical techniques employed during P-ATM validation efforts as representative of CAASD human performance measurement and analysis capabilities; specific experiment results reported in the cited references will not be repeated here.

Terminal Performance-Based Air Traffic Management (P-ATM) Improvement Validation. Although the P-ATM concept applies to all aspects of terminal operations, the focus of this analysis is the productivity gain associated with radar controller positions managing the Terminal Radar Approach Control (TRACON) airspace. To estimate the magnitude of these productivity gains, two HITL simulations of TRACON operations were conducted (Smith, 2007). The HITL simulations focused on five different combinations of radar positions (Feeder-Feeder, Final-Final, Departure-Departure, Feeder-Final and Departure-Feeder), and were performed using controllers that were currently or previously certified. Three key capabilities were simulated in the CAASD Integrated ATM laboratory: 1) Area navigation (RNAV) and Required Navigation Performance (RNP) routes, 2) precise metering at the TRACON boundary and from the runway, and 3) electronic data communications. Workloads and other effects were measured for three basic test conditions, including a preliminary baseline assessment. Variations to the P-ATM conditions, such as preplanned upset events and weather were also simulated.

In this study, researchers deployed both SAGAT and a unique measure of human information processing alongside other measures of workload such as the time spent on the frequency by the controller. The information processing method demonstrated working memory loads in terminal controllers under conditions with and without the P-ATM tools. In general, this study captured valuable P-ATM concept refinements and promising results, it was also clear that there is a need to address more sophisticated automation aspects of the terminal P-ATM concept to explore the impacts of more aggressive upset events, and apply P-ATM in other terminal environments.

P-ATM Operational Feasibility and Benefits Assessment. This HITL experiment (Winokur, Bowen, and Scott, 2006) was conducted using high fidelity prototypes of today's En Route sector automation as well as the enhanced ATC automation proposed for the 2015 timeframe. Within the constraints of a laboratory environment, the experiment enabled an assessment of the feasibility of certain aspects of the concept of future En Route sector operations (P-ATM). It also allowed the direct comparison of subjective workload estimates between a baseline operational condition and a condition reflecting future NAS operations.

There were two primary objectives for this HITL experiment: 1) to estimate the productivity improvements that could be realized in High Performance Airspace (HPA) as a result of enhanced ground and airborne capabilities and of the changes in operating procedures that those capabilities would enable and 2) to begin assessing the operational feasibility and acceptability of key elements of the future En Route sector concept of operations for HPA. While allowing for an initial validation of the concept, the experiment also sought to assess whether the expected benefits were realized by the concept.

The experiment participant team was comprised of twelve FAA Front Line Managers, all with recent ATC experience and possessing an extensive range of operational knowledge and expertise. To allow for a comparative assessment of controller workload and an assessment of concept feasibility, the participants conducted a series of single-staffed operations under two different conditions: Baseline Automation (BA) and Enhanced Automation (EA). During each operational trial, participants assumed the role of sector controller and were expected to safely and efficiently manage the traffic under their control. Supported by the sector automation, and in accordance with the related operational procedures, the controller performed required tasks and duties under a variety of workload conditions. These tasks included: ensuring aircraft separation, maintaining flight plans, responding to pilot requests and coordinating with other sectors (as appropriate).

Several types of data were collected both during and after operational trials. Subjective measures included workload ratings, operational acceptability ratings, and debriefing sessions. The ATWIT is a workload rating scale designed for use in ATC studies. For this experiment, ATWIT was administered approximately every five minutes by the simulation software. The NASA-TLX is a widely-used, general-purpose workload rating scale consisting of multiple subscales. Following each operational trial, participants rated the workload of the entire run using NASA-TLX. In summary, the NASA-TLX ratings provided an estimate of the average workload for the entire trial, whereas the ATWIT ratings provided estimates of workload levels as they changed throughout the trial.

In general, this experiment enabled the objective measurement of controller productivity improvements based on the operational use of a critical set of automation enhancements as well as fundamental changes in sector operations. Furthermore, the experiment enabled a subjective assessment of key elements of the future En Route concept and a comparative assessment of workload between two operational conditions. The analysis of the feedback collected indicates that the sector concept of operations for HPA was valid and feasible and would yield substantial productivity improvements.

Large Terminal Radar Approach Control (TRACON) Environments. This evaluation (Klein, 2007) consisted of terminal ATC operations simulated in the CAASD Integrated ATM laboratory using certified FAA terminal radar controllers to manage traffic in a large, busy TRACON in accordance with the practices and procedures outlined in the FAA Air Traffic Control order 7110.65R. Participants were provided with varying levels of additional automation support which represented evolutionary steps towards a possible future ATC environment as part of a Performance-based ATM concept. The automation experimental variations consisted of baseline operations similar to a vectoring environment of today, operations within RNAV procedures which contained lateral, vertical and speed guidance (RNAV condition), operations with RNAV procedures and enhanced arrival metering (P-ATM Lite condition), and operations with RNAV procedures, enhanced arrival metering, deviation alerts and data communications (P-ATM condition).

Again, several types of data were collected both during and after operational trials. Subjective measures included workload ratings, operational acceptability ratings, and debriefing sessions. For this experiment, ATWIT was administered approximately every five minutes by the simulation software. Following each operational trial, participants rated the workload of the entire run using the NASA-TLX. In summary, the TLX ratings provided an estimate of the average workload for the entire trial, whereas the ATWIT ratings provided estimates of workload levels as they changed throughout the trial.

The effect of the independent variables in this evaluation (automation, position combinations) was measured using a number of subjective and objective dependent variables, or evaluation metrics. The subjective measures included real-time and post-simulation workload ratings as well as post-simulation questions and discussions. The objective measures were obtained from recorded communications between participants and pseudo-pilots, and the simulated flight tracks. In general, the results of this experiment identified more optimal combinations of departure and feeder positions and noted the need for more analysis to extend simulation results to TRACONS with different complexity levels.

Results from P-ATM En Route HITL Experiments. This series of experiments is a continuation of evaluation activities from the previous year that assessed the feasibility of key elements of the P-ATM concept of operations for the full data communications environment, known as HPA. These two experiments (Klein, 2007) focused on understanding the viability of the P-ATM concept with respect to the following: handling severe weather situations, responding to capability failures and exception events, and managing aircraft with mixed levels of communications performance.

The participants in these experiments comprised nine of the twelve Front Line managers that took part in the evaluation activities of the previous year. The nine participants manage traffic in En Route facilities across the country, possess an extensive range of operational knowledge, and are required to remain current in their respective airspace. Unlike the previous year's experiments which were designed to estimate productivity gains, one of the objectives of this experiment was to illustrate the effect that adverse conditions had on sector operations. In other words, because the experiment allowed for the measure of controller workload under a more realistic and challenging set of conditions (than presented in the previous year), the results from the two experiments can be compared to analyze the impact that these conditions have on controller workload.

In addition to assessing concept feasibility and controller workload, the third objective of the HPA experiment was to determine if there were any additional operational requirements that were necessary to support the controller in the wide variety of situations examined. For example, while handling a medical emergency, the controller may require access to certain information and automation capabilities to safely and efficiently handle the flight. Therefore, the experiment provided the opportunity for participants to identify any operational needs that were not currently specified in the concept. This type of feedback is considered essential to refining the P-ATM concept such that it can be sued as a foundational element for system requirements definition and evolution.

In contrast to the previous year's evaluation, where controllers managed traffic under a baseline condition and a condition reflecting the operational conditions at an En Route sector in the future NAS, in this experiment, the participants operated only under the latter condition. As in preceding experiments, several types of data were collected both during and after operational trials. Subjective measures included workload ratings, operational acceptability ratings, and debriefing sessions. The ATWIT was administered approximately every five minutes by the simulation software. Following each operational trial, participants rated the workload of the entire run using TLX. In general, the results of these experiments extended previous validation the P-ATM concept of operations for HPA to encompass the handling of severe weather situations (including the implementation of Traffic Management Initiatives (TMIs)) and the management of capability failures and exceptions.

Situational Awareness in Future TRACON Environments. Previous HITL simulations of P-ATM operations in TRACON environments conducted by CAASD have shown favorable reductions in controller workload; however controller detection of simulated pilot deviations, which were included to ensure the controllers were maintaining a vigilant state even in reduced workload operations, was delayed or missed. Accordingly, this controller HITL evaluation (Smith, 2007) was conducted to isolate out what may be impacting controller SA to determine if ground automation enhancements to supplement the terminal controller's SA in future operations are needed. This exploratory controller HITL simulation was conducted with six Front Line Managers from various TRACON facilities as participants. The experiment's objective was to understand the contributions of RNAV operations and increased traffic levels to a change in controller SA.

Assessments of controller SA were compiled based on two quantitative measures: administration of the SAGAT and detection performance related to simulated pilot deviations. The controller positions evaluated included four feeder (approach) positions and two departure positions. Baseline and RNAV operational conditions were both conducted in both moderate and a high traffic levels managed by each controller. The manipulation of traffic was accomplished by combining like sectors of airspace, normally combined in low traffic periods, in busy traffic periods. Airport capacity and traffic demand remained a constant across all simulation conditions. As part of the RNAV operational test condition, a third variable (the constant display of the RNAV procedure when managing operations) was also manipulated to evaluate its benefit to maintaining controller SA.

Although the controllers were queried using SAGAT over several aspects of the traffic situation, only the query responses that represented the most fundamental level of SA were evaluated. These included traffic recall and the recall of aircraft flight parameters, specifically altitude, heading, speed, and lateral position. Traffic recall reflects the results of the query that requested the controller to specify the location of all known aircraft for which the controller had responsibility for at the time the simulation was paused. In general, for arrival operations, results indicated that the increased number of traffic operations was the driver of a change in SA. Overall SAGAT recall of traffic, lateral position, and heading in RNAV operations were generally as good as or better than data from baseline operations when a moderate level of traffic was managed. For departure operations, results also indicated that the increased number of traffic operations was the driver of a change in SA. Overall traffic recall, lateral position recall and accuracy, and altitude recall and accuracy for RNAV operations were generally as good as or better than data from baseline operations with moderate traffic levels.

Surface Safety Logic

Controller and Pilot Response Times to Runway Safety Alerts. A 2009 MITRE study developed a response time model for runway safety alerts (incorporating both the tower and flight deck, see Figure H-4). The model was developed to be used to ensure that surface safety systems would allow for enough time for humans to react to alerts generated by the system. The tower HITL simulation consisted of eleven controllers (active and retired) who participated in eight scenarios each, with four of the scenarios containing runway incursions. The response time was measured from the time the alert went off to the time the controller took action. The mean response time for controllers was found to be 4.6 seconds (Sanchez, Smith, and Chong, 2009).

The initial model development did not take into account variables that could affect reaction times. However, in 2010, observations, focus groups, field data analysis, lab walkthroughs, and HITL simulations that incorporated visibility and alert reliability variables were conducted so a validation plan for the model could be developed. Once the model is validated, it can serve as a tool to compare response times to safety alerts while fatigued to response times to safety alerts while well-rested (Sanchez, Smith, and Stevens, 2010).

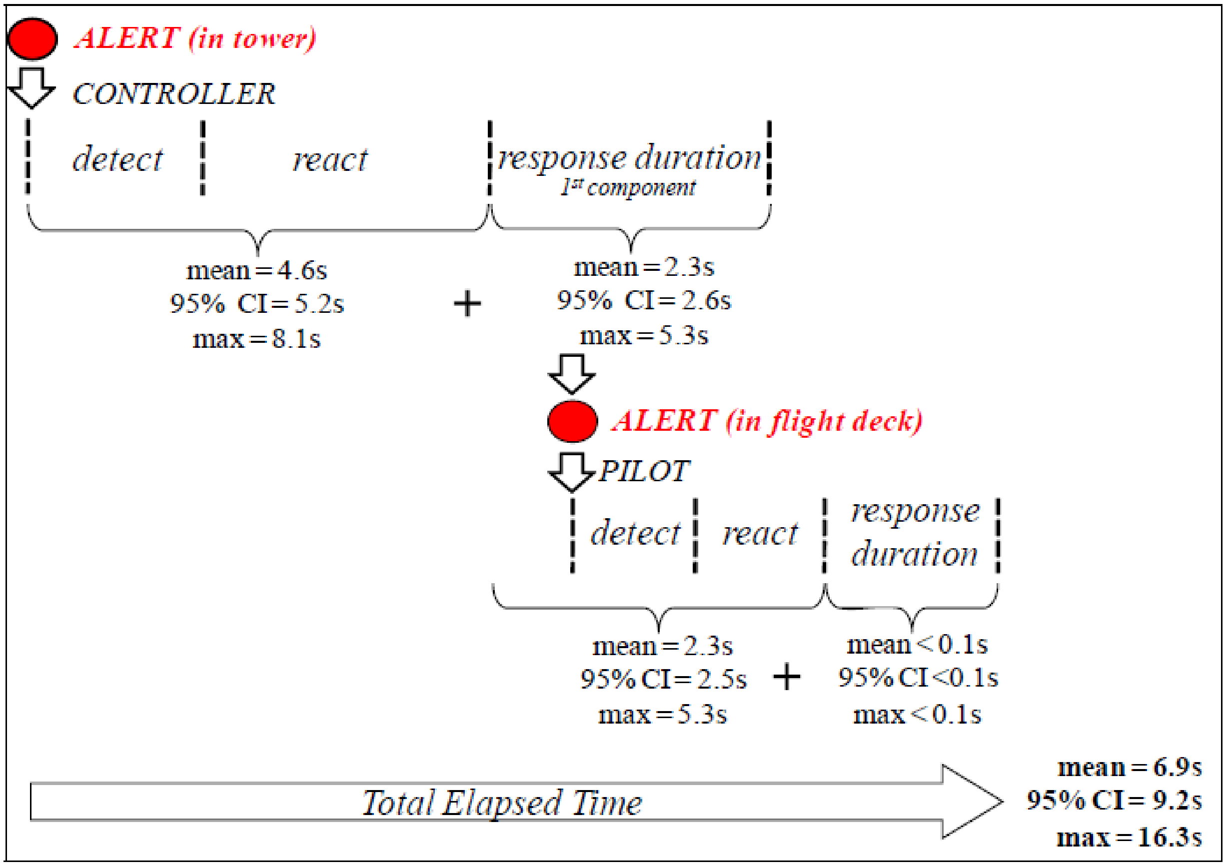

Figure H-4. Response Time Model

To collect information on situations that affect response time, a HITL simulation will be conducted that will closely simulate working conditions by lasting 8 hours (the length of a shift). Ideally, active controllers from towers with ASDE-X (Airport Surface Detection Equipment, Model X) or AMASS *(*Airport Movement Area Safety System) will be participants and will have a minimum of one year of on-the-job training (Sanchez, Smith, and Stevens, 2010).

Terminal Trainer

Background. As more recent FAA concerns emerged over the quality and duration of Terminal air traffic controller training, in coordination with FAA, CAASD developed and fielded a Terminal Trainer as a "spin-off" of its enrouteTrainer concept. In conjunction with FAA, CAASD, more recently, identified training needs for terminal ATCs similar to those that precipitated development and field evaluation of the prototype enrouteTrainer platform—the Terminal Trainer.

Terminal Trainer Prototype Field Evaluation Report. A Terminal Trainer prototype was field evaluated by CAASD and FAA at the Miami TRACON in late 2008. As with the enrouteTrainer, the objectives of the Terminal Trainer field evaluation were to assess the usability and benefits of integrating advanced training technologies and techniques into the delivery of site-specific airspace training. During the evaluation, the overall acceptability of the system and its ability to successfully deliver the training curriculum were assessed. The operational utility and acceptability of the specific, individual Terminal Trainer capabilities (e.g., simulation, games, drawing tools, etc.) were also evaluated.

Seven students participated in the evaluation. Four of the students participated in the first evaluation session while the other three took part in the second. None of the students had any controller experience prior to coming to the facility's training program. For the conduct of the evaluation, the students were asked to start with the Terminal Trainer's Overview lesson and then progress through the airspace lesson for each position presented. The students were given five days to use the Terminal Trainer to learn airspace for eight positions. Prior to use of the prototype, each group of students was provided with a half day of evaluation training. Over the course of the five days, each group of students was expected to learn, study, and review the airspace using the prototype and could progress at their own pace. At some point during the second to last day, the students were given an airspace test to measure their progress.

Data were collected both during and after each evaluation session using observation, questionnaires, and usage data. After the students completed the training they were administered the questionnaire by the CAASD facilitators. Feedback was also collected from the Miami instructor responsible for one of the classes. Analysis of the data collected shows that overall the Terminal Trainer was rated high in terms of usefulness by both students and the instructor who was administered the questionnaire (Vu and Weiland, 2009).

Terminal Trainer Prototype Initial Field Evaluation Plan for Potomac TRACON. Continued research with the Terminal Trainer to extend and validate the results from the Miami filed study was conducted at Potomac TRACON (PCT) in August 2010. Students in the Mount Vernon Area (MTV) of PCT received training for nine radar positions with the Terminal Trainer as well as the Special Flight Rules Area (SFRA), and airline memorization information that as tested via a game (the airline memorization game was also used on students from other areas). The Terminal Trainer was used in lieu of classroom instruction for parts of the MTV students' syllabus. The Terminal Trainer collected objective evidence, observations were done, and subjective information from students and instructors solicited (Weiland, 2010).

Tower Approach Clearance Analysis. A functional analysis of Staffed NextGen Tower (SNT) Operations was performed in 2009 as the first step in a safety assessment of SNTs. To perform the analysis, the functions that ATCs in the towers perform today were characterized. A functional hierarchy was then developed and functional flow and N^2 diagrams were created for the different functions of the hierarchy. The hierarchy and diagrams that were products of the functional analysis are expected to be useful for hazard identification and risk assessment and mitigation in future SNT work (Cheng, Nene, and Diffenderfer, 2010). Section 1.1.0 of the functional hierarchy developed was 'Manage Arrival Traffic,' and its corresponding functional flow diagram is depicted in Figure H-5 (Cheng, Nene, and Diffenderfer, 2010).

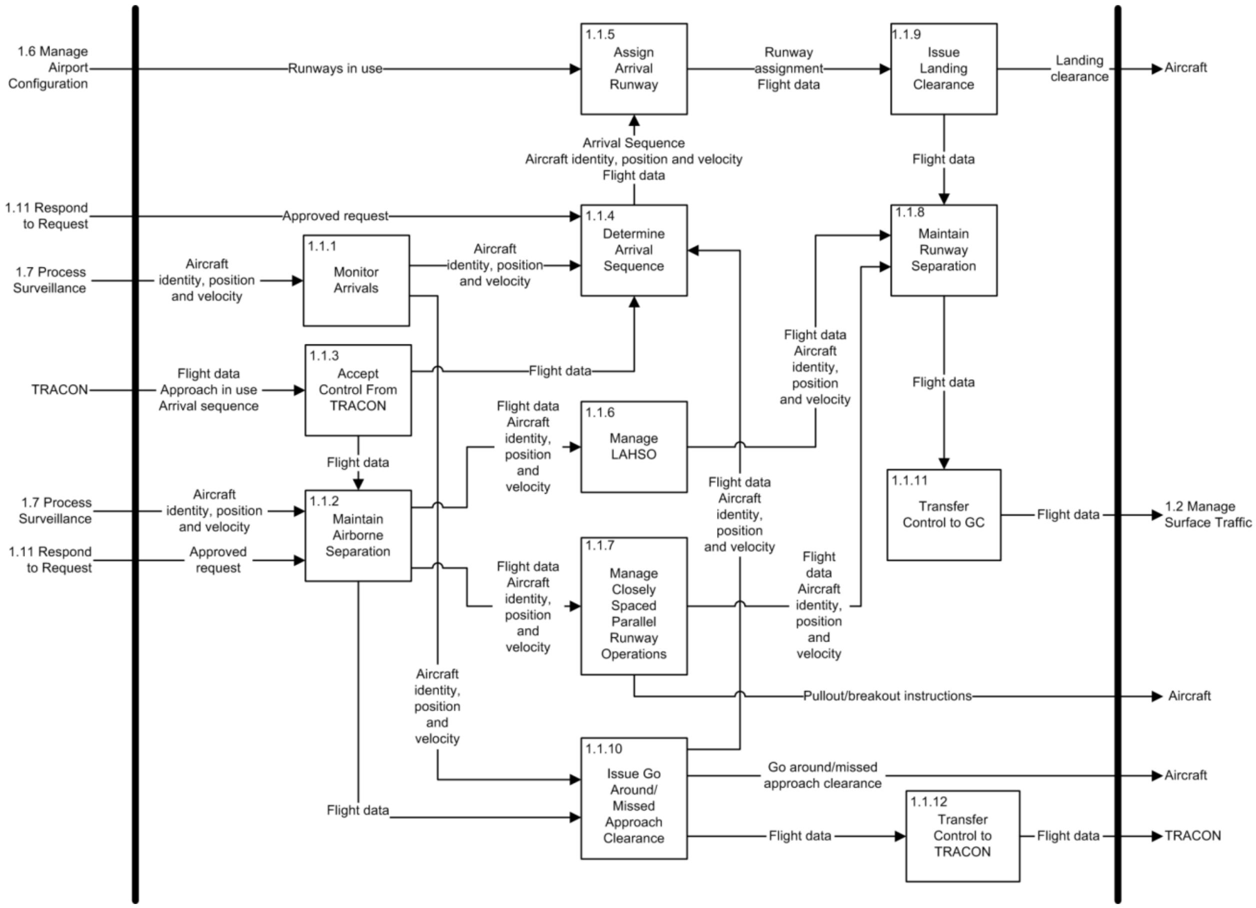

Figure H-5. Manage Arrival Traffic

In addition to the functional flow diagrams, N^2 diagrams were created using the functional flow diagrams and a visual representation of the functional interfaces of the system. The second level N^2 diagram 'Mange Arrival Traffic' is shown in Figure H-6. Functions are on the diagonal, inputs are above or below a function. Outputs are on the left or right of the function. External outputs are shown in the first row and external inputs are shown in the first column (Cheng, Nene, and Diffenderfer, 2010).

	Aircraft Identity, position and velocity	Aircraft Identity, position and velocity, Request	Flight Data, Approach in Use, Arrival Sequence	Approved Request, Procedures	Runway(s) in Use							
	1.1.1 Monitor Arrivals			Aircraft identity, position and velocity						Aircraft identity, position and velocity		
		1.1.2 Maintain Airborne Separation				Flight Data Aircraft identity, position and velocity	Flight Data Aircraft identity, position and velocity			Flight Data		
		Flight data	**1.1.3 Accept Control From TRACON**	Flight Data								
				1.1.4 Determine Arrival Sequence	Arrival Sequence Aircraft identity, position and velocity Flight data							
					1.1.5 Assign Arrival Runway				Runway Assignment, Flight Data			
						1.1.6 Manage LAHSO		Flight Data Aircraft identity, position and velocity				
Pullout/Breakout Instructions							**1.1.7 Manage CSPR Operations**	Flight Data Aircraft identity, position and velocity				
								1.1.8 Maintain Runway Separation		Flight Data Aircraft identity, position and velocity	Flight Data	
Landing Clearance									**1.1.9 Issue Landing Clearance**		Flight Data	
Go Around Instructions Missed Approach Clearance				Flight Data Aircraft identity, position and velocity						**1.1.10 Issue Go Around/Missed Approach Clearance**		Flight Data
Flight Data											**1.1.11 Transfer Control to GC**	
Flight Data												**1.1.12 Transfer Control to TRACON**

Figure H-6. N² Diagram of Manage Arrival Traffic

A HITL was performed with seven tower controllers at the FAA Technical Center's Airways Facilities Tower Integration Laboratory (AFTIL) simulator. The purpose of the HITL was to evaluate the effect of multiple landing clearance (MLC) caps on controller workload and workflow and safety effects. The controllers completed four, one-hour long scenarios with the landing clearance caps varying across the scenarios (no cap, 10 mile, 7 mile, and one active clearance per runway). In terms of safety, there were 11 confirmed operations errors and 7 possible OEs observed during the HITL. Additionally, controllers' attention was directed toward the Digital Bright Radar Indicator Tower Equipment (DBRITE) 20-30% more when caps were in place as compared to no cap being in place. Results of the HITL showed that workload and interruptions were increased under all cap conditions compared to the no cap condition as indicated by increased time on frequency of the controllers, modified transmission phraseology, and increased memory errors. Important to note, subjectively, controllers found the caps to be unacceptable (Estes, DeSenti, and Kamienski, 2010).

Appendix I Sleep Disorders

The types of sleep disorders potentially represented in the ATCS population are described in the following sections. These include: insomnias (see section I.1), sleep related breathing disorders (see section I.2), hypersomnias of central origin not due to a circadian rhythm sleep disorder, sleep related breathing disorder, or other cause of disturbed nocturnal sleep (section I.3), circadian rhythm sleep disorders (section I.4), parasomnias (section I.5), sleep related movement disorders (section I.6), and other sleep disorders (section I.7). Methods for the diagnosis of sleep disorders are presented in section I.8, the prevalence of each type of sleep disorder in section I.9, and what is known about sleep disorders in aviation in section I.10.

I.1 Insomnias

Insomnia is defined in the *ICSD-2* as "repeated difficulty with sleep initiation, duration, consolidation, or quality that occurs despite adequate time and opportunity for sleep and results in some form of daytime impairment" (American Academy of Sleep Medicine [AASM], 2005, pg. 1). The general criteria for an insomnia disorder include a. "complaint of difficulty initiating sleep, difficulty maintain sleep, or waking up too early or sleep that is chronically nonrestorative or poor in quality," which b. "occurs despite adequate opportunity and circumstances for sleep," and c. "at least one of the following forms of daytime impairment related to the nighttime sleep difficulty is reported by the patient," "fatigue or malaise; attention, concentration, or memory impairment; social or vocational dysfunction or poor school performance; mood disturbances or irritability; daytime sleepiness; motivation, energy, or initiative reduction; proneness for errors or accidents at work or while driving; tension, headaches, or gastrointestinal symptoms in response to sleep loss; concerns or worries about sleep" (AASM, 2005, pg. 2).

I.1.1 Adjustment Insomnia (Acute Insomnia)

Adjustment Insomnia is a short-term sleep disorder (not present longer than three months) that is a result of a reaction to a stressor. Patients may experience daytime sleepiness or insomnia. Sadness, anxiety, irritability, depression, and fatigue may also be present. This disorder can affect social and work life and may lead to drug or alcohol abuse. The disorder will subside once the stressor is eliminated or the patient is able to adapt (AASM, 2005).

I.1.2 Psychophysiological Insomnia

Psychophysiological insomnia is associated with worrying about falling asleep that prevents one from falling asleep and/or getting a good sleep. It results in non-refreshing sleep and daytime fatigue. This disorder affects quality of life. It can increase risk for a major depressive episode (recurrent or first) and decrease vigilance, attention, concentration, and energy (AASM, 2005; National Center on Sleep Disorders Research [NCSDR], 2003). The symptoms may lead to patient abuse of sleeping pills. Psychophysiological insomnia is more common in women (AASM, 2005).

As with other forms of insomnias, behavioral approaches including reduced intake of caffeine, tobacco, and other stimulants as well as good sleeping habits can help with symptoms. Cognitive Behavioral Therapy (CBT) has also been shown to make an improvement in patients with insomnia. Drug therapies include non-benzodiazepine hypnotics, benzodiazepine hypnotics, antidepressants, and supplements such as melatonin (Simon, 2009).

I.1.3 Paradoxical Insomnia

Paradoxical insomnia is a disorder that manifests in subjective complaints of insomnia in the absence of objective evidence from a PSG. Reported daytime function impairment by the patient is not as severe as would be seen in other insomnias. Paradoxical insomnia can lead to depression, anxiety, or hypnotic or other drug dependence (AASM, 2005).

It has been debated whether paradoxical insomnia should be differentiated from psychophysiological insomnia and the best treatment for it remains unknown as there are few studies, none of which have been randomized (Edinger and Krystal, 2003). There is also speculation that this may be a precursor to psychophysiological insomnia as one study found progressive differences in metabolic rate between normal sleepers, sleepers with sleep state misperception (aka paradoxical insomnia), and sleepers with psychophysiological insomnia (Bonnet and Arand, 1997). This observed difference in metabolic rate among the three groups as well as observed differences in Non rapid Eye Movement (NREM) EEGs in patients with paradoxical insomnia point to a possible physiological cause for this disorder (Krystal, Edinger, Wohlgemuth, and Marsh, 2002). Indeed, overactive central nervous system during sleep is a speculated predisposing factor (AASM, 2005).

I.1.4 Idiopathic Insomnia

Idiopathic insomnia is a life-long condition, often presenting in infancy, of which the cause is not known. It does not present with any other sleep, neurological, mental or other medical disorder, and is absent from behavioral issues or medication/drug use. Idiopathic insomnia is extremely rare, with an occurrence of 1% in the population (American Sleep Association, 2007). Patients may experience detrimental effects to their attention, concentration, and mood and are at an increased risk for major depression. Patients may turn to drug or alcohol use to counteract the insomnia and fatigue (AASM, 2005).

Good sleep hygiene can be beneficial for patients with this disorder; CBT may also helpful. Medications (specifically hypnotics) are sometimes used, but will not cure the condition and have been shown to be problematic for patients with this condition (Schutte-Rodin, 2005).

A student pilot of the Australian Defense Forces was removed from flight duty and recommended to be removed from the military upon diagnoses of idiopathic insomnia after eliminating other sleep disorder possibilities. He was also considered to possibly have narcolepsy or delayed sleep phase disorder, both of which would have resulted in the same decision (Smart and Singh, 2006).

I.1.5 Insomnia Due to Mental Disorder

Insomnia due to mental disorder is generally related to mood, anxiety or somatoform disorders. As insomnia is a typical symptom of these types of disorders, this diagnosis is only given when the insomnia involved warrants its own clinical attention. If the insomnia persists after resolution of the mental disorder, a different insomnia diagnosis should be given (AASM, 2005).

I.1.6 Inadequate Sleep Hygiene

Inadequate sleep hygiene is a result of lifestyles and work schedules and can cause insomnia and excessive sleepiness. Attention, concentration, vigilance, motivation, and/or mood may be detrimentally affected. It can lead to caffeine addiction, and/or alcoholism (AASM, 2005).

I.1.7 Insomnia Due to Drug or Substance

Insomnia due to drug or substance is insomnia that is caused by hypnotics or other medications, caffeine or other stimulants, illegal drugs, specific foods, environmental toxins, or alcohol. The insomnia can occur during use/exposure or after use/exposure (AASM, 2005).

Hypnotics and sedatives can cause excessive sleepiness and stopping them abruptly or developing a tolerance may lead to insomnia. Abuse of stimulants such as cocaine and amphetamine can result in insomnia and symptoms of excessive use can resemble schizophrenia. Caffeine is another stimulant that can cause insomnia. Additionally, antidepressants, pseudoephedrine, antihypertensives, anatiparkinsons, and antiepileptic medications as well as numerous medications can cause insomnia. Food allergies can also lead to insomnia, and though it is primarily seen in childhood, adults can be affected. Exposure to toxins from metal or organic origin can lead to excessive sleepiness or insomnia, depending on whether the toxin causes central nervous system excitation or depression. While alcohol can reduce sleep latency, the subsequent sleep is generally restless and if one stops using alcohol as a sleep aid after becoming dependent, insomnia and potential life-threatening withdrawal symptoms may result (AASM, 2005).

I.1.8 Insomnia Due to Medical Condition

Insomnia due to medical condition is insomnia that accompanies a medical condition and causes enough distress to require its own clinical attention. Pulmonary disorders, obstructive lung diseases, sleep-related asthma, neurological disorders and disorders that cause pain are some conditions that can result in insomnia (AASM, 2005).

I.1.9 Insomnia Not Due to Substance or Known Physiological Condition, Unspecified (Nonorganic Insomnia, NOS)

Insomnia not due to substance or known physiological condition, unspecified is for insomnia that is thought to be caused by mental or psychological issues, or practices not conducive to sleep, that cannot be classified as one of the other insomnias because it does not meet the criteria. It also may be diagnosed temporarily while more information is collected to determine the cause of the insomnia (AASM, 2005).

I.1.10 Physiological (Organic) Insomnia, Unspecified

Physiological (organic) insomnia, unspecified is insomnias that is thought to be caused by a medical problem, physiological state, or substance that cannot be classified as one of the other insomnias because it does not meet the criteria. It also may be diagnosed temporarily while further examinations are performed to determine the specific cause of the insomnia (AASM, 2005).

I.2 Sleep Related Breathing Disorders

SRBDs are defined by the *ICSD-2* as “characterized by disordered respiration during sleep,” (AASM, 2005, pg. 33).

I.2.1 Central Sleep Apnea Syndromes

Primary Central Sleep Apnea. Primary central sleep apnea (CSA) is indicated by more than five per hour cessations of breathing and effort to breathe while transitioning from wakefulness to NREM sleep, but can occasionally be seen during NREM sleep in some patients. Its cause is unknown. Primary CSA disturbs sleep with frequent arousals and can cause excessive sleepiness or insomnia, leading to cognitive and memory impairment (AASM, 2005).

Treatment options that have shown some level of success in patients with Primary CSA include bi-level positive airway pressure (BPAP), acetazolamide (a carbonic anhydrase inhibitor), oxygen therapy, CPAP combined with increased carbon dioxide, and inhaled carbon dioxide (Becker, Wallace, 2010; Eckert, Jordan, Merchia, and Malhotra, 2007).

Central Sleep Apnea Due to Cheyne Stokes Breathing Pattern. Cheyne stokes breathing pattern (CSB) is a breathing pattern seen during sleep marked by apneas and hypopneas that alternate with hyperpneas that are accompanied by a crescendo-decrescendo pattern of tidal volume and is most commonly seen in patients with heart failure (AASM, 2005; Eckert, Jordan, Merchia, and Malhorta, 2007; Yumino and Bradley, 2008). It is more common in men, being seen only rarely in women and patients are usually 60 years or older (AASM, 2005). The breathing pattern is most commonly seen in the transition from wakefulness to NREM sleep and also during sleep stages 1 and 2. It causes frequent arousals and EDS (AASM, 2005; Eckert, Jordan, Merchia, and Malhorta, 2007).

Oxygen therapy and carbon dioxide administration have been shown to improve CSB in short-term trails, though more research on the safety of long-term treatment is needed, as well as the effect the treatments have on the generally co-present heart failure. Treatment of the heart failure can also improve CSB (Eckert, Jordan, Merchia, and Malhorta, 2007).

Central Sleep Apnea Due to High-Altitude Periodic Breathing Pattern. High-altitude periodic breathing can occur at altitudes of 5000 meters and occurs in almost everyone at altitudes of 7600 meters or greater. It causes cycles of central apneas and hyperpneas seen during NREM sleep. Breathing will gradually return to normal over time with acclimatization but at extremely high altitudes may persist until descent. High-altitude periodic breathing causes frequent arousals throughout the night, reducing stage 3 and 4 sleep, and commonly results in fatigue or excessive sleepiness (AASM, 2005). Treatments include oxygen therapy, acetazolamide and theophylline (Becker and Wallace, 2010).

I.2.2 Obstructive Sleep Apnea Syndromes

Obstructive Sleep Apnea, Adult. Obstructive sleep apnea (OSA) is the repeated full or partial collapse of the pharyngeal airway while sleeping. This collapsing results in apneas and hypopneas that result in lowered blood oxygen saturation and cause a patient to wake up to resume breathing (AASM, 2005; Punjabi, 2008). The continuous arousals lead to disrupted sleep which affects cognitive performance and causes symptoms of EDS, fatigue, and/or insomnia (AASM, 2005; NCSDR, 2003). Other symptoms that may be present in patients with OSA include snoring, witnessed apneas, nocturnal choking, nocturia (frequent nighttime urination), impotence, memory impairment, morning headaches and nausea, personality changes, and depression (McNicholas, 2008).

Apneas and hypopneas are most common during rapid eye movement (REM) sleep and stage 1 and 2 of NREM sleep, but can occur during any stage (AASM, 2005). Deep sleep is related to increased upper airway dilator muscle activity and thus while a patient is in slow wave sleep they will experience fewer events (Eckert and Malhotra, 2008). An apnea is a cessation of breathing that lasts at least 10 seconds (Punjabi, 2008). A hypopnea is reduced airflow; however, there is discrepancy in relation to the degree of reduction in airflow, oxygen desaturation and the EEG arousal required to be considered a hypopnea, and in fact, no exact definition exists (Ruehland et al., 2008). Most apneas and hypopneas last 10 to 30 seconds and extremes can last a minute or more (AASM, 2005). Severity and diagnosis of OSA is determined by the AHI aka the respiratory distress index (RDI), which is the number of apneas and hypopneas per hour of sleep. Mild OSA is $5 \leq AHI \leq 15$, moderate is $15 \leq AHI \leq 30$, and severe is $AHI > 30$ (Epstein et al., 2009). The lack of a consistent definition of a hypopnea has been shown to lead to considerable differences in AHI and thus affect identification and severity classification, treatment decisions, estimates of OSA prevalence and public health impact, determination of comorbidities as well as treatment payment (Ruehland et al., 2008). Further, severity as determined by a PSG (AHI) has been shown to only be weakly associated with subjective reports of symptoms. This suggests that objective and subjective information should be used to determine OSA severity and subsequent treatment options (Weaver, Kapur, and Yueh, 2004). It is also noteworthy that patients with OSA have been shown to be at an increased risk for car crashes compared to normal controls. There is, however, discrepancy as to whether the severity of the OSA or subjective sleepiness ratings can predict the risk of crashes in patients with OSA (Tregear, Reston, Schoelles, and Phillips, 2009; Mulgrew et al., 2008).

OSA can be diagnosed with either a *polysomnography (PSG) or home portable monitoring (PM) a*ccording to a standard from the American Academy of Sleep Medicine's Adult Obstructive Sleep Apnea Task Force. The Task force also came to a consensus that PM should only be used in patients without comorbidities and who through pretesting have been determined to likely have moderate to severe OSA or in patients with extenuating circumstances which would not make a PSG feasible/possible. Also, there was a consensus that PM should only be used as part of a comprehensive sleep evaluation. When testing for OSA a PSG needs to record an EEG, electrooculogram (EOG), airflow, respiratory effort, oxygen saturation, chin electromyogram, and either HR or an ECG; and may record leg electromyography (EMG) derivations and/or body position. PSGs should be performed by a registered member of the Board of Registered Polysomnographic Technologist or an equivalent. Scoring should be done using the *AASM Manual for the Scoring of Sleep and Associated Events* (Epstein et al., 2009).

As stated, a PM must only be used as a part of a comprehensive sleep evaluation and that evaluation must be supervised by a board certified or eligible practitioner of sleep medicine (Collop et al., 2007; Epstein et al., 2009). The PMs' sensors should be applied by a sleep medicine technologist/technician or another trained healthcare professional or one of the said individuals must educate the patient on the application. PMs testing for OSA must record blood oxygenation, airflow, and respiratory effort (Collop et al., 2007; Epstein et al., 2009) and raw data must be reviewed by a board certified or eligible sleep medicine practitioner (Collop et al., 2007). The AHI of a PM is the number of apneas and hypopneas divided by the total recording time rather than the total sleep time, and thus there is the potential for underestimation and subsequent false negatives. If the PM does not indicate a diagnosis of OSA in patients with high pretest likelihood, a PSG should be performed (Collop et al., 2007; Epstein et al., 2009). The MSLT, actigraphy and autotitrating positive airway pressure (APAP) are not recommend by the AASM Task Force for the diagnosis of OSA, though the MSLT and actigraphy may provide useful supplemental information (Epstein et al., 2009). In support of this, actimetry has been shown to underestimate respiratory-related arousals in patients with OSA (Wang et al., 2008).

While a PSG or a PM as part of a comprehensive sleep evaluation meeting the aforementioned requirements are the only acceptable methods for diagnosing OSA according to the AASM, there have been studies investigating the use of other devices or screening methods for the detection of OSA. One study compared the accuracy of SNAP (SNAP Laboratories International, LLC) with a PSG to assess its reliability in the detection of OSA in the lab. SNAP records oronasal airflow and sound, respiratory effort, pulse oxygenation and heart rate. SNAP and PSG agreed in 83.9% of the patients who had an RDI ≥ 15. Inter-rater reliability was cited as a problem for the SNAP, however, the authors concluded that SNAP was an alternative for detecting OSA in the lab in patients without comorbidities who have a high probability of having OSA. It was noted that further studies comparing the SNAP at home to PSG results to be necessary before at-home screening with the device could be recommended (Su, Baroody, Kohrman, and Suskind, 2004). A different study found both unattended and attended home studies (using the ApnoeScreen-I, CNS-Jaëger), which recorded airflow, position, oxygen saturation, pulse, and actimetry) to be less expensive than in-lab PSGs. Results from the home studies and PSG had an agreement in 75% of the patients. The cheapest option was an in-home study attended by a technician as 33% of the unattended home studies yielded no interpretable results, which would thus result in an in-lab PSG being necessary (Golpe, Jiménez, and Carpizo, 2002). Another study found a single channel nasal flow monitor (Flow Wizard, Diagnose IT) to be useful for detecting or ruling out OSA. The authors felt that it had promise for the research-domain, but as it was not as accurate as in-lab PSGs, should not be used to diagnose (Wong et al., 2008). In a comparison of a single channel flow monitor (ApneaLink™, ResMed Corporation) with a PSG for the detection of OSA in patients with type 2 diabetes found that the ApneaLink™ had a sensitivity of >80% at all AHI levels. The results from the PSG and ApneaLink™ agreed the most at an AHI ≥ 15. The authors concluded the device would be useful for detecting OSA in patients with a high probability of the disorder or in patient groups where SRBDs are known to flourish (Erman, Stewart, Einhorn, Gordon, Casal, 2007).

The treatments available to patients with OSA include positional therapy, weight loss, avoidance of alcohol and other central nervous system depressants, oral appliances (OAs), surgery, or positive airway pressure (PAP). Sometimes a combination of some of these treatments is the best option. Positional therapy can incorporate the use of special pillows designed to alleviate snoring and mild apnea, it can also be a positional alarm that will go off when a patient begins to sleep on his or her back; various other home remedies to prevent someone from sleeping on the back can be used. Weight loss can be effective in mild cases of sleep apnea and can help to reduce the severity in others (American Sleep Apnea Association [ASAA], 2007). OAs are best for non-obese people with mild sleep apnea and either work to move the lower jaw forward (mandibular repositioning device (MRD)) or to keep the tongue from obstructing the airway (tongue retaining devices (TRD)), or both (Rogers, 2000; ASAA, 2007). Complications include permanent mandibular posture shifting with a MRD, and tongue soreness with TRD. Discomfort of the temporomandibular joint may also be seen in patients with either OA (Rogers, 2000). Surgery works to open the airway so that occurrence of obstruction is reduced (ASAA, 2007). PAP is the treatment of choice for all levels of severity of OSA and should be applied nasally (preferred), orally, or oronasally. It may be CPAP, BPAP, or APAP with CPAP being the most common. OAs may be used in patients that either do not respond to CPAP, prefer an OA or cannot use CPAP. Surgery is a good choice for patients with mild OSA that have an anatomical abnormality that could be fixed and lead to resolution of the OSA, it may also be done if CPAP treatment is inadequate. The surgery done would depend on the patient's anatomy.

Ongoing follow-up should be done in all patients to check on efficacy, compliance, side effects, and complications (Epstein et al., 2009), and PMs can be used to monitor the response of patients to treatments other than CPAP (surgery, OAs, and weight loss) (Collop et al., 2007). Successful pharmaceutical treatments for OSA have not yet been discovered, but the area has had some promising preliminary results and it is likely that research will continue (Carley, Olopade, Rugit, and Radulovacki, 2007; Hedner, Grote, and Zou, 2008; Marshall et al., 2008; Epstein et al., 2009). A study comparing CPAP combined with conservative measures, OAs combined with conservative measures, and conservative measures alone (weight loss and sleep hygiene information) in patients with mild to moderate OSA ($5 < AHI < 20$ with a $ESS > 9$ or $AHI > 20$) found CPAP and OAs combination therapies to significantly improve AHI, and CPAP combination therapy to significantly improve arousal index, but conservative measures alone were not found to significantly improve AHI or arousal index. While ESS ratings significantly decreased in patients in all three therapy groups, CPAP combination therapy was shown to improve symptoms of EDS the most (Lam et al., 2007).

In terms of compliance, it has been shown that patients with greater ESS scores, oxygen desaturation scores and AHI have significantly higher levels of compliance with CPAP therapy (that is, those with regular use versus occasional or no usage have significantly higher scores on these measures). Speculation as to the reasons why less severe OSA leads to lower compliance includes the idea that those patients who experience less severe OSA (in both subjective and objective measures) may not notice much improvement with the CPAP therapy and therefore judge it as unnecessary. The risks of untreated OSA need to be stressed to these and all patients

(Yetkin, Junter, and Gunen, 2008). Studies have not found consistent predictors of CPAP compliance (Weaver and Grunstein, 2008). Also to note, in patients with severe apnea as determined by an AHI >30 but with no subjective sleepiness, CPAP was not found to improve arterial blood pressure, quality of life, MSLT score, attention, memory, vigilance, visuomotor coordination, nor information processing (Barbé et al., 2001). OSA has been connected to cardiovascular issues and possible links to insulin resistance, stroke, heart attack and congestive heart failure have been made (NCSDR, 2003). While medical complications of OSA cannot be ignored, there are perhaps more relevant issues related to OSA for the aviation industry. For example, patients with OSA have been shown to have decreased brain activation compared to normal controls on a sustained attention task. Interestingly, AHI was not shown to relate to slower reaction times and decreased brain activation in task-related brain areas but rather the arousal index was. This would suggest that sleep fragmentation influences the effects on vigilance and attention in patients with OSA more than hypoxia does and should perhaps play a greater role in determining the risks that a patient with untreated OSA poses to the transportation industry (Ayalon, Ancoli-Israel, Aka, McKenna, and Drummond, 2009).

Recently, areas of the transportation industry have begun looking at ways to screen for OSA and other sleep disorders. The rail industry had workers fill out the ESS that was included in their medical recertification pack (workers renew their medical every three years). An ESS score of >10 was used as the cutoff to identify workers at-risk for EDS and OSA. At-risk workers were shipped a device that recorded AHI, oxygen saturation, sleep/wake state, and body position for one night, worker then shipped the device back. Of the 40% of workers who were identified as at-risk, 80% were identified as positive for OSA by the device (Gerson, Barnett, and Holland, 2009).

In the commercial driving industry in Israel has evaluated the possibility of using BMI to screen for EDS. In a study, drivers who were identified to have a BMI ≥ 32 during their medical were referred and underwent a MSLT and PSG. While none of the 153 drivers reported having symptoms of EDS or OSA, 116 (75.8%) were diagnosed with OSA. Based on the findings, the Traffic Safety Department of the Ministry of Health in Israel added BMI to the required medical exam as a first-line screen for EDS. A PSG and MSLT are performed on those drivers with a BMI ≥ 32 and if the MSLT indicates EDS, the driver's license is suspended until CPAP therapy or weight loss is initiated (Dagan, Doljansky, Green, and Weiner, 2006). In the United States, the Joint Task Force of the American College of Chest Physicians, American College of Occupational and Environmental Medicine, and the National Sleep Foundation, developed recommendations regarding the screening, diagnosis, treatment, compliance and effectiveness, return to work, and follow-up for commercial drivers with OSA. They recommend that drivers should be medically qualified if the driver either has no suggestive factors or positive diagnosis of OSA or has been diagnosed and treated with CPAP and is compliant. The Joint Task Force recommends an in-service evaluation and a maximum 3 month certification if the driver has symptoms consistent with OSA; has two of the following three: 1) a BMI ≥35 kg/m^2, 2) neck circumference >17 inches (men) or > 16 inches (women), or 3) new hypertension, uncontrolled hypertension or hypertension that requires two medications or more to control; has an ESS >10; has been diagnosed with a sleep disorder and is lacking compliance information; or has 5 < AHI < 30 on a PSG even without a EDS, accidents or hypertension. Finally, the Joint Task Force recommends an out-of-service immediate evaluation if the driver has observed or confessed EDS; an accident that has been attributed to a probable sleep disturbance; an ESS ≥ 16 or a Functional Outcomes of Sleep Questionnaire (FOSQ) <18; or an AHI > 30 (Hartenbaum et al., 2006).

The Japan Civil Aviation Bureau issued a circular to airlines regarding the prevention of accidents related to OSA after a rail accident was attributed to the driver falling asleep due to OSA. One airline sent OSA information to crews and published medical information about OSA in their company magazine. The airline's medical service division decided to gather possible OSA symptoms during medical exams. Cockpit crew members are asked about severe snoring, EDS, involuntary naps, and apneas. If OSA is suspected a two hour daytime PSG is performed. Of nine crew members identified by the screening to possibly have OSA, three cases were confirmed with an all-night PSG (Numata et al., 2005).

I.2.3 Sleep Related Hypoventilation/Hypoxemia Syndromes

Sleep Related Nonobstructive Alveolar Hypoventilation, Idiopathic. Sleep related nonobstructive alveolar hypoventilation, idiopathic is a rare disorder marked by lowered alveolar ventilation and oxygen saturation during sleep that is not related to any medical condition and whose cause is unknown. The disorder causes frequent arousals, and may lead to excessive sleepiness and/or insomnia. The hypercapnia and hypoxemia that results from the hypoventilation is worse during REM sleep. This disorder may contribute to the development of heart failure and hypertension (AASM, 2005). Treatments include BPAP, oxygen therapy, or a combination of the two (Townsend, 2006b).

I.3 Hypersomnias of Central Origin Not Due to a Circadian Rhythm Sleep Disorder, Sleep Related Breathing Disorder, or Other Cause of Disturbed Nocturnal Sleep

Hypersomnias of central origin not due to a circadian rhythm sleep disorder sleep, related breathing disorder, or other cause of disturbed nocturnal sleep are defined by the *ICSD-2* as "disorders in which the primary complaint is daytime sleepiness and in which the cause of the primary symptom is not disturbed nocturnal sleep or misaligned circadian rhythms" (AASM, 2005, p. 79).

I.3.1 Narcolepsy With Cataplexy

Narcolepsy with cataplexy (sudden loss of muscle tone associated with a strong emotion) is marked by abnormal REM sleep, cataplexy, and excessive sleepiness. Hypnagogic hallucinations, sleep paralysis, disturbed nocturnal sleep, memory lapses, and REM sleep behavior disorder are commonly seen in patients with narcolepsy with cataplexy. Automatic behavior may also be observed. Patients with narcolepsy with cataplexy experience involuntary sleep attacks at inappropriate times as well as frequent voluntary naps (AASM, 2005; Broughton, 1989; NCSDR, 2003). Sleep attacks are often precluded by hypnagogic hallucinations and sleep paralysis and altered states of consciousness but are rarely followed by sleep inertia (Broughton, 1989). Narcolepsy with cataplexy can affect jobs, social life, and education, and depression is common (AASM, 2005). There does appear to be a genetic component to narcolepsy with cataplexy (AASM, 2005; NCSDR, 2003).

Drugs for symptoms should be used in conjunction with behavioral approaches such as scheduled naps and a regular sleep schedule. Drugs used include the stimulant modafinil for the EDS, and antidepressants (tricyclics and selective serotonin reuptake inhibitors (SSRIs)), and gamma hydroxybutyrate (GHB) for cataplexy (National Institute of Neurological Disorders and Stroke [NINDS], 2010b).

I.3.2 Narcolepsy Without Cataplexy

Narcolepsy without cataplexy manifests the same symptoms as narcolepsy with cataplexy, except cataplexy is absent. Even so, cataplexy-like episodes are possible (AASM, 2005). Stimulants such as modafinil are commonly used to combat the EDS, and should be supplemented with behavioral approaches (NINDS, 2010b).

I.3.3 Narcolepsy Due to Medical Condition

Narcolepsy due to medical condition is marked by EDS and is caused by a medical problem. Cataplexy, hypnagogic hallucinations, sleep paralysis, or insomnia can be present but are not required. Multiple sclerosis, myotonic dystrophy, Parkinson’s disease, sarcoidosis, Prader-Willi syndrome, and Coffin-Lowry syndrome are just some of the diseases that have been shown to cause narcolepsy (AASM, 2005).

I.3.4 Narcolepsy, Unspecified

Narcolepsy, unspecified is a diagnosis that is used temporarily while the cause of the narcolepsy is unknown (AASM, 2005).

I.3.5 Recurrent Hypersomnia (Including Kleine-Levin Syndrome and Menstrual-Related Hypersomnia)

Recurrent hypersomnia is a very rare sleep disorder indicated by recurring periods of excessive sleepiness. The episodes occur weeks or months apart and last for days or weeks. Two forms of this disorder are Kleine-Levin syndrome and menstrual-related hypersomnia. The episodes affect a patient’s social and work life and may lead to depression (AASM, 2005; Kristo, 2006).

Recurrent hypersomnia appears to decrease in occurrence, length and severity over time, however, this is based on case studies and formal long-term evaluations of patients with this disorder have not been done (AASM, 2005; Kristo, 2006). There has been some success in preventing future occurrences with the use of lithium or carbamazepine (NINDS, 2009). Additionally, a case study revealed that vitamin B_{12} may be an effective treatment for at least Kleine-Levin syndrome (Yamada, 1995). Further, birth control may help in women with Menstrual-Related Hypersomnia (Kristo, 2006).

I.3.6 Idiopathic Hypersomnia With Long Sleep Time

Idiopathic hypersomnia with long sleep time is indicated by severe excessive sleepiness that is disabling to the sufferer during the day. Patients sleep anywhere from 10 to 14 hours with little disruption and difficulty waking. Patients also take deep extended naps during the day that are unrefreshing but do not experience sleep attacks like narcoleptics. Sleep drunkenness and confusional arousals are common (AASM, 2005; Broughton, 1989). A genetic component is assumed but has not been singled out. The disorder can significantly negatively affect work and social life, as well as education (AASM, 2005).

Treatment includes stimulants but they have been used with varying success. There is no cure but spontaneous resolution has been observed in a few patients (AASM, 2005). Behavioral approaches are recommended but have little impact on this disorder and medications are the main treatment, although they only relieve the symptoms. Drugs used include stimulants (i.e., modafinil, amphetamine). Other drugs used include dopamine agonists, antidepressants, and monoamine oxidase inhibitors) (NINDS, 2008).

I.3.7 Idiopathic Hypersomnia Without Long Sleep Time

Idiopathic hypersomnia without long sleep time is characterized by the same symptoms as idiopathic hypersomnia with long sleep time, except suffers sleep somewhere around 10 hours per night rather than 10 to 14 (AASM, 2005).

I.3.8 Behaviorally Induced Insufficient Sleep Syndrome

Behaviorally induced insufficient sleep syndrome is chronic sleep deprivation that is unintentional and a result of lifestyles and work schedules. It causes excessive sleepiness and hypnagogic hallucinations and sleep paralysis may or may not be present. Patients are at an increased risk for traffic accidents. Attention, concentration, vigilance, motivation, work performance, social life and/or mood may be detrimentally affected. It can lead to caffeine or other stimulant addiction (AASM, 2001).

I.3.9 Hypersomnia Due to Medical Condition

Hypersomnia due to medical condition is excessive sleepiness that is caused by a medical problem that most often involved the brain or nerves. Examples include stroke, encephalitis, head trauma, tumors, and neurodegenerative diseases. Endocrine and metabolic conditions can also cause this disorder (AASM, 2005).

I.3.10 Hypersomnia Due to Drug or Substance

Hypersomnia due to drug or substance is excessive sleepiness that results from use of, tolerance to, abuse of, or withdrawal from different drugs or substances such as stimulants or sedatives. It can be cause by illegal or prescription medications (AASM, 2005).

I.3.11 Hypersomnia Not Due to Substance or Known Physiological Condition (Nonorganic Hypersomnia, NOS)

Hypersomnia not due to substance or known physiological condition is excessive sleepiness and fragmented sleep that is not associated with a physiological condition or substance use. It generally is associated with mental conditions such as bipolar disorder, other mood disorders, schizoaffective disorder, personality disorder, adjustment disorder, or somatoform disorders. This disorder can cause detrimental effects to work and social life, and is commonly associated with decreased energy, social withdrawal, and lack of interest (AASM, 2005).

I.3.12 Physiological (Organic) Hypersomnia, Unspecified, (Organic Hypersomnia, NOS)

Physiological (organic) hypersomnia, unspecified, is excessive sleepiness that is presumed to be a result of a physiological conditions but that does not meet the criteria for any of the other hypersomnias (AASM, 2005).

I.4 Circadian Rhythm Sleep Disorders

Circadian rhythm sleep disorders result, according to the *ICSD-2*, “from alterations of the circadian timing system or a misalignment between the timing of the individual’s circadian rhythm of sleep propensity and the 24-hour social and physical environments” (AASM, 2005, p. 117). The general criteria for a circadian rhythm sleep disorder includes a. “a persistent or recurrent pattern of sleep disturbance due primarily to one of the following” “i. [a]lterations of the circadian timekeeping system,” “ii. [m]isalignment between the endogenous circadian rhythm and exogenous factors that affect the timing or duration of sleep,” that leads to b. “insomnia, excessive daytime sleepiness, or both,” and c. “is associated with impairment of social, occupational, or other areas of functioning” (AASM, 2005, p. 117).

I.4.1 Circadian Rhythm Sleep Disorder, Delayed Sleep Phase Type (Delayed Sleep Phase Disorder)

Circadian rhythm sleep disorder, delayed sleep phase type (DSP) is indicated by a regular sleep pattern that is delayed. Patients have great difficulty trying to fall asleep and wakeup at a societal normal time. This disorder can result in EDS in the morning if the patient tries to wake up at a normal time and insomnia at night if they try to fall asleep at a normal time (AASM, 2005; Sack et al., 2007). The disorder may lead to the abuse of stimulants, sedatives, hypnotics, or alcohol (AASM, 2005).

Bright light exposure at pre-determined times, melatonin administration at pre-determined times, chronotherapy (sleep schedule), vitamin B12, hypnotics, and stimulants all may be used to treat this disorder (Sack et al., 2007).

I.4.2 Circadian Rhythm Sleep Disorder, Advanced Sleep Phase Type (Advanced Sleep Phase Disorder)

Circadian rhythm sleep disorder, advanced sleep phase type (ASP) is indicated by a regular sleep pattern that is advanced and patients fall asleep and wake up earlier than the societal norm (AASM, 2005).

Bright light exposure at pre-determined times may be used to treat the disorder (AASM, 2005; Sack et al., 2007). Behavioral approaches may also be employed. Like DSP, abuse of stimulants, sedatives, hypnotics or alcohol may result from this disorder (AASM, 2005).

I.4.3 Circadian Rhythm Sleep Disorder, Irregular Sleep-Wake Type (Irregular Sleep-Wake Rhythm)

Circadian rhythm sleep disorder, irregular sleep-wake type, is characterized by multiple periods of sleep at different times of both the day and night with an average total sleep time comparable to other people in the patient’s age group. Symptoms of excessive sleepiness or insomnia are experienced between the sleep episodes. The pattern of sleep is unpredictable. This disorder may result from a lack of zeitgebers (i.e., light, social activities, eating). Mentally retarded children and sufferers of dementia, as well as institutionalized persons may be more susceptible (AASM, 2005).

Bright light therapy at pre-determined times, melatonin administration at pre-determined times, sleep hygiene, and CBT may be used to treat this disorder. Medications used include hypnotics, stimulants, melatonin, and vitamin B12 (Schutte-Rodin, 2006; Sack et al., 2007).

I.4.4 Circadian Rhythm Sleep Disorder, Free-Running Type (Nonentrained Type)

Circadian rhythm sleep disorder, free-running type, is characterized by free-running circadian rhythms that cause the patient to fall asleep an hour or two later each night. This disorder is very rare among the general population but is common among blind people (AASM, 2005).

For patients who are not blind, bright light therapy and melatonin administration at predetermined times have both been shown to be effective, and vitamin B12 has been successful for two patients. For blind patients, melatonin at pre-determined times has been shown to be effective, and chronotherapy worked for one patient (Sack et al., 2007).

I.4.5 Circadian Rhythm Sleep Disorder, Jet Lag Type (Jet Lag Disorder)

Circadian rhythm sleep disorder, jet lag type (jet lag disorder) is difficulty falling or staying asleep, accompanied by excessive sleepiness or insomnia and decreased performance that occurs after crossing two or more time zones. Extent of symptoms depends on the number of time zones crossed as well as the direction, with westward travel easier to adjust to compared to eastward. For each time zone crossed, approximately one day is needed to resynchronize; however, if more than six time zones are crossed, the circadian rhythm may shift in the opposite direction. This is generally a self-limiting disorder and treatment is not necessary (AASM, 2005).

I.4.6 Circadian Rhythm Sleep Disorder, Shift Work Type (Shift Work Disorder)

Circadian rhythm sleep disorder, shift work type (shift work disorder) is a result of rotating shifts or other irregular schedules. It results in excessive sleepiness and insomnia and can cause performance decrement and may negatively affect social and familial life. The sleep disturbances most likely result from a mismatch between the work schedule and the circadian rhythm. The constant disturbance of sleep may lead to drug or alcohol dependence to assist with sleeping and being awake (AASM, 2005). Shift work disorder has been linked to gastrointestinal issues, ulcers, cardiovascular disease, and breast cancer and compromised pregnancy in women. It may also be related to metabolic issues (Costa, 2009; Knutsson, 2003; Lee-Chiong, 2006).

The ability to adjust to the shift work will depend on the person and the schedule (AASM, 2005). Bright light exposure and melatonin are two ways to combat the effects of shift work disorder (Lee-Chiong, 2006).

I.4.7 Circadian Rhythm Sleep Disorder Due to Medical Condition

Circadian rhythm sleep disorder due to medical condition is a disturbed sleep-wake pattern that causes excessive sleepiness and insomnia and is a result of a medical or neurological problem. Dementia, Parkinson’s disease, blindness, and hepatic disease have all been associated with this disorder (AASM, 2005).

I.4.8 Other Circadian Rhythm Sleep Disorder (Circadian Rhythm Disorder, NOS)

Other circadian rhythm sleep disorder (circadian rhythm disorder, NOS) is a disorder of the circadian rhythm that results in EDS and/or insomnia and is not related to a drug or substance and does not meet the criteria of any of the other circadian rhythm sleep disorders (AASM, 2005).

I.4.9 Other Circadian Rhythm Sleep Disorder Due to Drug or Substance

Other circadian rhythm sleep disorder due to drug or substance is a disorder of the circadian rhythm that is due to a drug or substance and does not meet the criteria of any of the other circadian rhythm sleep disorders (AASM, 2005).

I.5 Parasomnias

Parasomnias are defined in the *ICSD-2* an “undesirable physical events or experiences that occur during entry into sleep, within sleep, or during arousals from sleep” (AASM, 2005, p. 137).

Sleep Related Eating Disorder. Sleep related eating disorder (SRED) is marked by out of control eating episodes that occur while partially awake and are usually partially remembered, but may not remembered at all or may be remembered vividly. Frequent episodes can result in insomnia and fatigue. Weird combinations of food, frozen or raw foods, toxic chemicals, or inedible items are usually consumed. If confronted during an episode, a sufferer may become agitated or irritated. This disorder can be idiopathic or may appear in conjunction with other sleep disorders like sleepwalking. It can also be induced by psychotropic medications. Injury may result from preparing foods or consuming toxic substances. SRED can result in depression and can also lead to such conditions as obesity and high cholesterol (AASM, 2005).

I.6 Sleep Related Movement Disorders

Sleep related movement disorders are defined by the *ICSD-2* as "conditions that are primarily characterized by relatively simple, usually stereotyped, movements that disturb sleep or by other sleep related monophasic movement disorders such as sleep related leg cramps" (AASM, 2005, pg. 177). It further states that "[n]octurnal sleep disturbance or complaints of daytime sleepiness or fatigue are a prerequisite for a diagnosis of a sleep related movement disorder" (AASM, 2005, pg. 117).

I.6.1 Restless Leg Syndrome

Restless leg syndrome (RLS) manifests itself in urges to move legs because of uncomfortable sensations that subsequently disturb sleep. It may be primary or secondary in nature (AASM, 2005; NCSDR, 2003). The secondary form can be associated with iron deficiency, pregnancy, and end-stage renal disease (NCSDR, 2003). RLS can cause quality of life issues and degrade work performance; it can also lead to insomnia, anxiety, depression, and social dysfunction (AASM, 2005; NCSDR, 2003). Drugs that may cause or worsen RLS include antihistamines, most antidepressants (excluding bupropion which increases dopamine), and dopamine-receptor antagonists (AASM, 2005).

Behavioral/lifestyle approaches such as less intake of caffeine, alcohol and tobacco, as well as iron, folate and magnesium supplements are generally suggested for mild to moderate RLS. Drugs used include dopaminergics, benzodiazepines, opioids, anticonvulsants, and presynaptic alpha2-adrenergic agonists (Anderson, 2009; NINDS, 2010a).

I.6.2 Periodic Limb Movement Disorder

Periodic limb movement disorder (PLMD) involves the involuntary movement of the limbs while asleep and causes excessive daytime fatigue. PLMD can have an impact on quality of life and work performance and patients may develop depression or anxiety due to the constant sleep disruptions and nonrefreshing sleep (AASM, 2005).

CBT may be effective in the treatment of PLMD. Common medications include benzodiazepines, dopaminergic agents, anticonvulsants, and skeletal muscle relaxants (Anderson, 2010).

I.6.3 Sleep Related Leg Cramps

Sleep related leg cramps are sudden, intense, painful muscle contractions that occur either before falling asleep or while sleeping. The cramps and the residual discomfort disturb sleep and massaging, stretching or applying heat to the muscle to relieve the cramp and can delay the return to sleep. People with certain diseases such as diabetes, metabolic disorders, endocrine disorders, neuromuscular disorders and vascular disease are more susceptible. Intense exercise, dehydration, electrolyte imbalance, birth control usage, and pregnancy can also be associated with sleep related leg cramps. Treatments for this disorder have not been developed (AASM, 2005).

I.6.4 Sleep Related Bruxism

Sleep related bruxism is the clenching and grinding of teeth while asleep. It can be primary or secondary. Jaw discomfort, teeth wear, and temporal headaches can result and severe or frequent bruxism can disturb sleep. Highly motivated and vigilant people, as well as people who are experiencing anxiety or stress, are more prone to this disorder (AASM, 2005).

An OA to protect the teeth is usually used in patients with sleep related bruxism. Stress management, relation techniques, and CBT can help to reduce stress and thus bruxism (Townsend, 2006c).

I.6.5 Sleep Related Rhythmic Movement Disorder

Sleep related rhythmic movement disorder is mostly seen in infants and children, it is rare in adults, but has been observed. It involves repetitive body movements that may include body rocking, head banging, and head rolling, and less frequently, body rolling, leg banging and leg rolling. These rhythmic movements occur while drowsy or asleep and are usually accompanied by humming or other sounds. These movements are very common in infants and children and this should diagnosis should only be used when the movements significantly interfere with sleep or daytime function, or they result in bodily injury (AASM, 2005).

I.6.6 Sleep Related Movement Disorder, Unspecified

Sleep related movement disorder, unspecified, is usually a temporary diagnosis when a psychiatric condition is suspected but more information is needed to confirm its presence. It may also be a permanent diagnosis when a patient has a sleep related movement disorder that does not meet the classification of any of the other sleep related movement disorders (AASM, 2005).

I.6.7 Sleep Related Movement Disorder Due to Drug or Substance

Sleep related movement disorder due to drug or substance is a temporary diagnosis when sleep related movements are a result of abuse of, dependence on, or side-effect of a drug, substance or toxin and is used until the specific substance is identified as well as if it is abuse, dependence or a side-effect (AASM, 2005).

I.6.8 Sleep Related Movement Disorder Due to Medical Condition

Sleep related movement disorder due to medical condition is usually a temporary diagnosis until the underlying medical condition is identified. It may be used as a permanent diagnosis if the presence of an underlying medical condition cannot be confirmed (AASM, 2005).

I.6.9 Isolated Symptoms, Apparently Normal Variants and Unresolved Issues

Isolated symptoms, apparently normal variants and unresolved issues include "sleep related symptoms that either lie at the borderline between normal and abnormal sleep that exist on the continuum of normal to abnormal events in sleep" and conditions that have "insufficient information … to include them as definite pathologies" (AASM, 2005, pg. 197).

I.6.10 Long Sleeper

Long sleepers sleep 10 to 12 hours a night and can experience EDS if they do not get enough sleep. Sleep architecture is normal and the long sleeping is not associated with a mental or physiological problem. Long sleepers can adapt and sleep less during the week and increase their sleeping periods to 12 to 15 hours on the weekends (AASM, 2005).

I.6.11 Excessive Fragmentary Myoclonus

Excessive fragmentary myoclonus is indicated by small movements of the corners of the mouth, fingers and toes that occur while sleeping. It can lead to disrupted sleep and thus daytime sleepiness or fatigue may result, with subsequent negative effects on concentration and memory (AASM, 2005). Clonazepam and anticonvulsants are used to treat this disorder (Townsend, 2006a).

I.7 Other Sleep Disorders

Other sleep disorders are ones that "cannot be classified elsewhere in the *ICSD-2*" (AASM, 2005, pg. 221).

I.7.1 Environmental Sleep Disorder

Environmental sleep disorder is caused by an external factor that causes a sleep disturbance leading to excessive sleepiness or insomnia. It is not related to a medical or psychiatric disorder, and removal of the factors leads to a sudden or gradual resolution of the disorder. It can negatively affect attention, concentration, vigilance, and/or mood and cause irritability and malaise (AASM, 2005).

I.8 Diagnosis of Sleep Disorders

Common sleep disorder complaints include insomnia, EDS and/or odd feelings, movements, or behaviors while asleep or during nocturnal awakenings. Movements or behaviors such as snoring, apneas, or kicking/twitching limbs occur while the patient is asleep. The patient is generally unaware of the occurrences unless a bed partner is disrupted. Symptoms like shortness of breath, leg cramps, or paralysis occur during nocturnal awakenings. A sleep disorder evaluation should begin with the complaint of the patient. Why is the patient seeking help and what for? Is it their complaint or is it a complaint of their bed partner? How long has/have the symptom(s) been experienced? What are the circumstances surrounding the symptoms? What improves or exacerbates the symptoms? These are all questions that should be asked. Patient bed time, sleep onset, awake time, and number and frequency of nocturnal arousals should be elicited. With shift workers, detailed sleep diaries are needed to look for findings consistent with circadian rhythm sleep disorders or insufficient sleep syndrome. Information regarding morning symptoms, daytime symptoms, naps, cataplexy, Hypnagogic hallucinations, automatic behavior and sleep paralysis should all be collected. Additionally, sleep setting questions should be asked to assess the possibility of environmental sleep disorder (Malow, 2005).

Complaints of insomnia include remarks about trouble falling and/or staying asleep, frequent arousals, or the inability to get back to sleep after early morning awakening. Different disorders can cause different types of insomnia. Sleep maintenance insomnia can be indicative of OSA. Insomnia present since childhood could mean idiopathic insomnia. If the insomnia is related to stress, adjustment sleep disorder may be the underlying disorder. Complaints of anxiety and/or frustration regarding the inability to fall asleep that resolves at an away from home location can point to Psychophysiological insomnia. Inadequate sleep hygiene may be seen in patients who have inconsistent bedtimes, exercise close to bed time, or use excessive caffeine throughout the day. The telltale sign of paradoxical insomnia is a complaint of not sleeping during eight hours of rest (Malow, 2005).

EDS is related to complaints of drowsiness that causes problems for the patient during the day or irresistible napping. The situations surrounding the sleepiness or napping can shed light on the disorder. Insufficient sleep syndrome can be ruled out with sleep/wake time information, with short sleep time during the work week and longer sleep on the weekends being indicative of it (Malow, 2005).

Snoring, gasping, and apnea can mean OSA. If a patient has experienced a loss of muscle tone with laughter or anger (cataplexy), narcolepsy is indicated. If a patient experiences insomnia and EDS they may have a circadian rhythm sleep disorder. Difficulty waking and falling asleep at night could be DSP, while evening sleepiness and early morning waking could be ASP. Jet lag disorder may be associated with travel and shift work disorder can be indicated by work schedule. Mental health questions can rule out insomnia due to mental disorder (Malow, 2005). In regards to movements and behaviors, bed partner testimony is essential as the specific behaviors and circumstances surrounding them need to be described (Malow, 2005).

A list of medications is needed, as some can alter the sleep structure. Herbal supplements, non-prescription medicines, and illegal drugs can all also affect the sleep structure and cause sleep disturbances. Medical and mental illnesses may also cause sleep disturbances or lead to the development of sleep disorders. Conditions such as hypothyroidism can contribute to the development of OSA and RLS and PLMD can be caused or worsened by renal disease or iron deficiency (Malow, 2005).

Family history is also essential in making a diagnosis, as some disorders like narcolepsy are genetic, and OSA and parasomnias can have genetic or familial influences. Information on social, occupational and school performance should be collected to assess the impact of the symptoms on life (Malow, 2005).

Underlying medical conditions that cause sleep disturbances should be ruled out through such things as psychiatric and neurological testing. After the evaluation, a differential diagnosis should be developed; the *ICSD-2* has a differential diagnosis listed with each disorder. Additional testing may need to be done to determine disease severity or to rule out diseases that may be on the differential. For instance, a MSLT can be used to confirm EDS and the severity of it. Finally, a PSG may need to be done to confirm the diagnosis of such disorders as OSA, narcolepsy, paradoxical insomnia, or PLMD (Malow, 2005).

I.9 Prevalence

For information on prevalence, see Table I-1. Noteworthy, one study found that people who worked nights or shift work had significantly more circadian rhythm sleep disorders and significantly more instances of insufficient sleep syndrome compared to people who worked a normal daytime schedule. Although not significant, night/shift workers also had more instances of insomnia (Ohayon, Lemoine, Arnaud-Briant, and Dreyfus, 2002).

Table I-1. Prevalence of Sleep Disorders[9]

Disorder	Prevalence	Gender Distribution	Age Information
Adjustment Insomnia	• General population: unknown, estimated 15-20% one-year prevalence rate in adults	• More common in women	• Occurs at any age • More common in older adults v. young adults and kids
Psychophysiological Insomnia	• General population: 1-2% • Clinical population: 12-15% *may be a secondary diagnosis in more patients	• More common in women	• More common in adolescents and adults • Rare in children
Paradoxical Insomnia	• General population: unknown • Clinical population: <5% of insomnia patients	• Unknown, assumed more common in women	• Seen mainly in young and middle aged adults • Low prevalence in children and adolescents
Idiopathic Insomnia	• Adolescents: ≈ 07% • Young adults: ≈ 1% • Older adults: unknown, probably consistent with above age groups • Clinical population: <10% of insomnia patients	• Unknown	• Presents during childhood, may not be diagnosed until older

[9] American Academy of Sleep Medicine, 2005, *The International Classification of Sleep Disorders, Second Edition, Diagnostic and Coding Manual*, Westchester, IL: American Academy of Sleep Medicine.

Disorder	Prevalence	Gender Distribution	Age Information
Insomnia Due to Mental Disorder	• General population: ≈3% • Clinical population: most common diagnosis of insomnia patients	• More common in women	• Highest rate in middle-aged adults • Less common in adolescents, young adults, and elderly
Inadequate Sleep Hygiene	• Adolescents and young adults: 1-2% • Older adults: unknown, probably consistent with above age groups • Clinical population: 5-10% of insomnia patients • * may be a secondary or primary in >30%	• Unknown	• Can present at any time from adolescence to adulthood
Insomnia Due to Drug or Substance	• General population: 0.2% • Clinical population: 3.5% of insomnia patients • * may be a secondary or tertiary diagnosis in more patients	• Unknown	• Related to stimulants more common in younger groups • Related to alcohol and sedatives more common in middle-aged and older groups • Related to side effects more common in those with known medical conditions in the middle-aged and older groups
Insomnia Due to Medical Condition	• General population: 0.5% • Clinical population: 4% • * ¼ of the clinical population may have this as a primary, secondary or tertiary diagnosis	• Unknown	• Occurs at any age • Most common in middle-aged and older
Insomnia Not Due to Substance or Known Physiological Condition, Unspecified	Data not provided, sometimes a temporary diagnosis		
Physiological (Organic) Insomnia, Unspecified	Data not provided, sometimes a temporary diagnosis		
Primary Central Sleep Apnea	• Unknown	• Seen more in men	• Most common in elderly and middle-aged

Disorder	Prevalence	Gender Distribution	Age Information
Central sleep Apnea Due to Cheyne Stokes Breathing Pattern	• Congestive heart failure population: 25-40% • Stroke population: 10%	• More common in men • Rare in women	• Usually seen in ages >60
Central Sleep Apnea Due to High-Altitude Periodic Breathing Pattern	• Unknown	• Probably more common in men	• Seen in almost anyone above 7600m and some below 5000m
Obstructive Sleep Apnea, Adult	• Depends on the criteria used to define OSA, with an AHI >5 coupled with EDS, 4% in men and 2% in women	• More common in men, ratio of 2:1	• Occurs at any age • Greatest increase in prevalence is seen from middle-aged to older groups
Sleep Related Nonobstructive Alveolar Hypoventilation, Idiopathic	• Unknown	• Probably more common in men	• Most often in appears in adolescence and young adulthood
Narcolepsy with Cataplexy	• US and Western Europe: 0.02-0.18%, lower in Israel, greater in Japan	• Slightly more common in men	• Occurs at any age, generally between age 15-25 • Usually not diagnosed until at least age 5
Narcolepsy without Cataplexy	• General population: unknown • Clinical Population:10-50% of narcoleptics	• Same in men and women	• Occurs at any age • Generally appears in adolescence
Narcolepsy Due to Medical Condition	• Unknown	• Unknown	• Unknown
Narcolepsy, Unspecified	Temporary diagnosis, data not provided		
Recurrent Hypersomnia	• Unknown, disorder is rare, only 200 documented cases	• 4:1 ratio favoring men in Kleine-Levin Syndrome	• Usually presents in adolescence
Idiopathic Hypersomnia with Long Sleep Time	• Unknown	• Appears to be the same in men and women	• Usually appears before age 25 • Rarely seen in children
Idiopathic Hypersomnia without Long Sleep Time	• Unknown	• Unknown	• Usually appears before age 25
Behaviorally Induced Insufficient Sleep Syndrome	• Not provided	• Same in men and women	• Occurs at any age • Presumably more frequent in adolescents

Disorder	Prevalence	Gender Distribution	Age Information
Hypersomnia Due to Medical Condition	• Unknown	• Unknown	• Unknown
Hypersomnia Due to Drug or Substance	• Unknown	• Unknown	• Related to stimulants generally presents between age 15-50 • Related to Alcohol presents at variable ages
Hypersomnia Not Due to Substance or Known Physiological Condition (Nonorganic Hypersomnia, NOS)	• Clinical population: 5-7% of hypersomnia patients	• More common in women	• Generally seen between age 20-50
Physiological (Organic) Hypersomnia, Unspecified, (Organic Hypersomnia, NOS)	• Not provided	• Not provided	• Not provided
Delayed Sleep-Phase Disorder	• General population: unknown • Young adults/adolescents: 7-16% • Clinical population: 10% of insomnia patients	• Not provided	• Usually onsets around age 20 • More common in young adults/adolescents • Has been seen in children
Advanced Sleep-Phase Disorder	• General population: unknown • Middle-aged and older groups: ≈1%	• Same in men and women	• Usually presents in middle-age • Occurrences increase with age • Has been seen in children
Irregular Sleep-Wake Rhythm	• Unknown	• Unknown	• Occurs at any age
Nonentrained Type	• General population: unknown, rare in sighted people • Blind population: >50%	• Appears to be the same in men and women	• Occurs at any age
Time Zone Change (Jet Lag) Syndrome	• Unknown	• Same in men and women	• Affects everyone, elderly may experience more severe symptoms
Shift Work Disorder	• General population: assumed to be ≈2-5%	• Appears to be the same in men and women	• Not provided

Disorder	Prevalence	Gender Distribution	Age Information
Circadian Rhythm Sleep Disorder Due to Medical Condition	• Dependent on condition	• Dependent on condition	• Dependent on condition
Other Circadian Rhythm Sleep Disorder (Circadian Rhythm Disorder, NOS)	• Not provided	• Not provided	• Not provided
Other Circadian Rhythm Sleep Disorder Due to Drug or Substance	• Not provided	• Not provided	• Not provided
Sleep Related Eating Disorder	• Eating Disorders Population Inpatient : 16.7% • Eating Disorders Population Outpatient : 8.7% • University population: 4.6%	• More common in women	• Generally presents between age 22-29, appears to be chronic
Restless Legs Syndrome	• Northern European population: 5-10%, lower in Indian and Asian populations	• Seen 1.5 times more in women	• Occurs at any age • Patients usually seek help after age 40
Periodic Limb Movement Disorder	• Unknown	• Appears to be the same in men and women	• Occurs at any age
Sleep Related Leg Cramps	• Unknown	• Unknown	• Occurs at any age, but most frequently in the elderly • 6% of people older than age 60 experiences cramps nightly
Sleep Related Bruxism	• Children: 14-17% • Adolescents to young adults: 12% • Young adults to middle-aged adults: 8% • Elderly: 3%	• Appears to be the same in men and women	• Most frequent in children, and prevalence decreases with age
Sleep Related Rhythmic Movement Disorder	• Infants: 53% • Adults: Rare	• Appears to be the same in men and women	• Common in infants, usually resolves by age 5
Sleep Related Movement Disorder, Unspecified	Data not provided, usually temporary diagnoses		

Disorder	Prevalence	Gender Distribution	Age Information
Sleep Related Movement Disorder Due to Drug or Substance	Data not provided, a temporary diagnoses		
Sleep Related Movement Disorder Due to Medical Condition	Data not provided, usually a temporary diagnoses		
Long Sleeper	• Men: 2% • Women: 1.5%	• More common in men	• Generally presents in childhood and is lasting
Excessive Fragmentary Myoclonus	• Clinical population: 5-10% of patients with EDS	• More common in men	• Most common in adults
Environmental Sleep Disorder	• General population: unknown • Clinical population: <5%	• Unknown	• Occurs at any age • Higher risk for the elderly

I.10 Sleep Disorders in Aviation

The knowledge that OSA and other sleep disorders pose a threat to the safety of the transportation system is not new. In 1995, the NTSB and NASA Ames Research Center held a fatigue symposium at which it was acknowledged that sleep disorders and especially sleep apnea were critical issues for the transportation industry. Dr. Pack from the Center for Sleep and Respiratory Neurobiology at the University of Pennsylvania Medical Center suggested that as the interest in the area moved forward, the topics that needed to be acknowledged included if sleep apnea should be screened for as an employment condition in the transportation industry and how that would be done cost effectively; whether a professional who was diagnosed would be paid disability; and if an accident resulted from untreated OSA, what the responsibility of the employer and employee would be. It was predicted that these questions would become the center of debate in the coming years. Dr. Pack also felt that awareness regarding the symptoms and treatment of OSA needed to be increased among the industry's employees, employers, and safety officials. He especially felt that there needed to be an increase in education for the medical examiners and that following the educational initiative, statistics on diagnosis should be kept. He also suggested that the medical forms ask questions specific to symptoms and physical indicators of OSA. Cost-effective ways to screen for OSA were also identified as a need (Pack, 1995). Even prior to this symposium, an article in Human Factors and Aviation Medicine entitled "Snoring—Danger Signal in the Sky" discussed symptoms of OSA and self-help tips for snoring, as well as treatment options for OSA. Notably, the article identified OSA (in its severe form) as a disorder that "can cause debilitating fatigue which as a flight crew member, can affect his or her safe operation of an aircraft" (Lipman, 1991, pg. 3).

The *International Classification of Sleep Disorders*, *Second Edition, Diagnostic and Coding Manual*, (*ICSD-2*) published by the American Academy of Sleep Medicine, classifies sleep disorders into eight categories, Insomnias; Sleep Related Breathing Disorders; Hypersomnias of

Central Origin Not Due to a Circadian Rhythm Sleep Disorder, Sleep Related Breathing Disorder, or Other Cause of Disturbed Nocturnal Sleep; Circadian Rhythm Sleep Disorders; Parasomnias; Sleep Related Movement Disorders; Isolated Symptoms, Apparently Normal Variants, and Unresolved Issues; and Other Sleep Disorders (AASM, 2005). This is not intended to be an exhaustive list of all sleep disorders, only those that may affect aviation. For example, disorders of childhood and/or infancy are not included as they would not be expected to affect aviation transportation employees.

I.10.1 Sleep Disorders and Aviation - Civil

Sleep Disorders and Air Traffic Controllers. According to JO 7210.3V, "[p]ersonnel actively engaged in the separation and control of air traffic, including Traffic Management Coordinators (TMCs) must possess a current medical clearance" (FAA, 2008, pp. 2-8-1). To hold a medical clearance they must meet the requirements of FAAO 3930.3, Air Traffic Control Specialist Health Program and Title 14 CFR Pt. 65 and Pt. 67. Additionally, "ATCSs assigned to AFSSs/FSSs in Alaska are also required to be evaluated under and meet the requirements of FAAO 3930.3" (FAA, 2008, pp. 2-8-1). In terms of medical clearances, ATCSs may be qualified, qualified with special consideration, disqualified, medically restricted, or incapacitated. Further, their medical status at any time may be full duty, medically restricted, medically disqualified or incapacitated (FAA, 1996).

Sleep Disorders in Airmen. All airmen wishing to exercise the privileges of airline transport pilot, commercial pilot, private pilot, recreational pilot, flight instructor, flight engineer, flight navigator, or student pilot certificates must hold a valid appropriate medical certificate (Medical Certificates: Requirement and Duration, 2010). Title 14 CFR Pt. 67 provides the medical standards for certification for the three types of medical certificates (first-, second- and third-class) (Medical Standards and Certification, 2010). Although the standards do differ to an extent, the disorders in this document would require the same course of action to be taken regardless of class. Medical certificates can be denied, reversed, unrestricted, with limits, or special issuances (T. Neal, personal communication, September 17, 2010).

Incidents Involving Sleep Disorders. At least one incident has been identified in which a member of the flight crew having a sleep disorder of the flight crew was part of the probable cause. go! Flight 1002 from Honolulu International Airport to General Lyman Field in Hilo, HI on February 12, 2008 overflew its destination by 26 nautical miles. The probable cause as determined by the NTSB was the captain and the first officer falling asleep. Undiagnosed OSA of the captain as well as the flight crew's work schedules were contributing factors (NTSB, 2009a). According to the NTSB's factual report, the pilot was evaluated after the incident and subsequently diagnosed as having severe OSA (NTSB, 2009b).

Following this incident, the NTSB sent a letter to the FAA that included recommendations on screening for OSA during medical certification exams. In the letter, the NTSB pointed out that all federal agencies overseeing passenger transportation in the U.S. currently or soon will gather information related to OSA in their operators. The NTSB recommended that the FAA make changes to the Application for Airman Medical Certificate in an effort to gain information about diagnosed OSA and also risk factors for OSA in airmen and prospective airmen. Additionally, it was recommended that a program be implemented to identify applicants who would be considered at high risk for the disorder and require them to provide documentation that they have been screened, and if OSA is present, treated effectively before they are issued an unrestricted certificate. Guidelines about identification and treatment of OSA in high risk airmen were also recommended to be developed for airmen, physicians and employers (NTSB, 2009c).

Standards for Airmen and ATC. If any information elicited during the course of a medical exam causes the Aviation Medical Examiner (AME) to determine that the airman or ATCS's ability to safely perform his or her duties may be affected, the AME can disqualify the airman or controller.

For ATCS applicants: FAAO 3930.3 Appendix 1, paragraph f (3) states that "[t]he applicant must have no other organic, functional or structural disease, defect or limitation found by the Federal Air Surgeon to clinically indicate a potential hazard to safety in the Air Traffic Control System. A pertinent history and clinical evaluation, including laboratory evaluations will be obtained and when clinically indicated, special consultations or examinations will be accomplished" (FAA, 1996, Appendix 1, pg. 4). However, FAAO 3930.3 also provides protocol for reconsideration if an initial applicant is determined to be medically disqualified. Chapter 2 paragraph 44 allows the applicant to request to be reconsidered by the Regional Flight Surgeon (RFS). If, after the reconsideration, the applicant has still been determined to be disqualified, he or she may request a review by the Federal Air Surgeon (FAA, 1996). The Federal Air Surgeon's decision will be final.

For ATCS: FAAO 3930.1 Appendix 1, paragraph F (3) states "Other Medical Conditions - must have no other organic, functional or structural disease, defect or limitation found by the Federal Air Surgeon to clinically indicate a potential hazard to safety in the Air Traffic Control System. A pertinent history and clinical evaluation including laboratory screening will be obtained, and when clinically indicated, special consultations and examinations will be accomplished" (FAA, 1996, Appendix 1, pg. 10). If, at a periodic requalification examination, an ATCS does not meet the medical standards, he or she may be granted a special consideration under Chapter 1 paragraph 23 of the FAAO 3930.3. If the ATCS is determined to be temporarily medically incapacitated, he or she can be put on leave or assigned administrative duties until he or she is determined to be medically qualified once again. If the ATCS is determined to be permanently medically disqualified, he or she may be reassigned to a staff position that does not require him or her to be medically qualified, or he or she is referred to the Personnel Management Division (FAA, 1996). For medical problems that are identified between medical exams, the Flight Surgeon will examine the ATCS or evaluate the relevant medical information to determine the medical status of the ATCS. If an ATCS is determined to be medically restricted or incapacitated he or she will either be placed on leave or be assigned administrative duties. ATCSs that are restricted will be reevaluated every 30 days. Incapacitated ATCSs or those who expect a recovery period of more than 30 days or disqualified ATCS are reviewed by the Air Traffic Control Division. ATCSs who have a temporary medical condition who cannot control will be placed on leave or assigned administrative duties; if they can control, they may get a special consideration. The status of the ATCS will be reevaluated at periodic intervals. ATCSs that are determined to have a permanent medical condition will either be assigned a staff position that does not require medical standards to be met, or will be referred to the Personnel Management Division (FAA, 1996).

For airmen: 14 CFR Parts 67.113, 67.213, and 67.313 (the general medical condition requirements for the first-, second- and third- class medical certificates) state that the medical standards include "(b) No other organic, functional, or structural disease, defect, or limitation that the Federal Air Surgeon, based on the case history and appropriate, qualified medical judgment relating to the condition involved, finds—(1) Makes the person unable to safely perform the duties or exercise the privileges of the airman certificate applied for or held; or (2) May reasonably be expected, for the maximum duration of the airman medical certificate applied for or held, to make the person unable to perform those duties or exercise those privileges. (c) No medication or other treatment that the Federal Air Surgeon, based on the case history and appropriate, qualified medical judgment relating to the medication or other treatment involved, finds— (1) Makes the person unable to safely perform the duties or exercise the privileges of the airman certificate applied for or held; or (2) May reasonably be expected, for the maximum duration of the airman medical certificate applied for or held, to make the person unable to perform those duties or exercise those privileges (Medical Standards and Certification, 2010).

However, Title 14 CFR Pt. 67.401 outlines the requirements for getting a special issuance medical certificate. If a person does not meet the standards in Part 67 subparts B, C, or D (the guidelines for first-, second-, and third class medical certificates) he or she may be able to get a special issuance at the discretion of the Federal Air Surgeon (see 14 CFR Pt. 67.401 for complete information) (Special Issuances of Medical Certificates, 2010). Further, there does exist some guidelines for certain disorders in the AME guide in terms of protocol for special issuances for airmen. These are presented in the following sections.

Sleep Apnea. Sleep apnea is initially disqualifying under Title 14 CFR Pt. 67.113, 67.213, 67.313. According to the AME guide, the initial special issuance decision will be done by the Federal Air Surgeon after all medical information regarding the condition is submitted. Current status of the sleep apnea, a sleep study with a PSG, and the medications used as well as the results from a titration study must be submitted. If the Federal Air Surgeon decides that the applicant would be able to perform the duties allowed by the medical certificate class without a threat to public safety he or she may grant a special issuance (FAA, 2006, p. 25; FAA 2009b, p. 5; FAA, 2010a, p. 62). After the initial special issuance, all subsequent special issuances may be AME Assisted Special Issuances (AASI). This may be done if the FAA has authorized an AASI and if the AME receives a report from the treating physician of the sleep apnea discussing the current treatment and symptoms and also comments about daytime sleepiness. If treatment compliance is speculated, a MWT is required. An AME may not grant an AASI if the compliance or effectiveness of the current therapy is questioned, the results of the MWT indicate a sleep deficiency and/or an illness associated with the sleep apnea has developed. In these cases, the decision on a special issuance has to be deferred to either the Aerospace Medical Certification Division (AMCD) or the RFS (FAA, 2006, p. 25).

Periodic Limb Movement Disorder. Periodic Limb Movement disorder is initially disqualifying under Title 14 CFR Pt. 67.113, 67.213, 67.31. The decision to grant a special issuance must be deferred to the AMCD or RFS. The applicant must submit all medical records related to the disorder including the status of the disorder, results of a sleep study with PSG and the medications used as well as the results from a titration study and a statement from the physician regarding RLS (FAA, 2009b, p. 5; FAA, 2010a, p. 62).

Treatments. The FAA does not maintain a published list of approved medications. When determining whether to grant a medical certificate or special issuance medical certificate, the underlying condition the medication is treating contributes the same or greater to the decision (FAA, 2009c, p. “Pharmaceutical Medications”). In the AME Guide, there is some guidance on medication categories but it explicitly states that “[t]his list is not meant to be totally inclusive or comprehensive. No independent interpretation of the FAA’s position with respect to a medication included or excluded from the following should be assumed” (FAA, 2009c, p. “Pharmaceutical Medications”).

When making a decision regarding whether or not to grant a special issuance, all aspects of the condition and all medical records related to the medical condition will be taken into account (Special Issuance of Medical Certificates, 2010). That being said, some of the classes of medications used for treatment of the disorders discussed in this document including sedatives, anxiolytics, tranquilizers, antipsychotic drugs, antidepressants, analeptics and hallucinogens are stated to be disqualifying and decision to grant an airmen a special issuance would have to be deferred to the AMCD or RFS (FAA, 2010b, p. 119).

I.10.2 Sleep Disorders and Aviation—Military

Military medical standards differ amongst the branches as well as among different flight personnel (which encompasses pilots, other aircrew, ATCs, and unmanned aerial system operators, among others). The medical standards for the branches are found in the following documents: Army—Army Regulation 40-501; Navy—Manual of the Medical Department, U.S. Navy, NAVMED P-117, Chapter 15; Army and Navy contract ATC - Office of Personnel Management Operating Manual: Qualification Standards for General Schedule Positions, GS–2152: Air Traffic Control Series; Air Force—Air Force Instruction 48-123; Coast Guard—Coast Guard Medical Manual, Commandant Instruction M6000.1D, Chapter 3. Additionally, guidelines on waivers for some medical issues, including some of the sleep disorders, are published by the Army (Aeromedical Policy Letters), Navy (U.S. Navy Aeromedical Reference and Waiver Guide) and Air Force (Air Force Waiver Guide). Table B-2 contains a list of the sleep disorders previously identified as causing fatigue, EDS, and/or insomnia. If the disorder is disqualifying, the part of the regulation that the disorder would be disqualifying under is listed.

Table I-2. Sleep Disorders Causing Fatigue, EDS, and/or Insomnia

	Army[10]			Army/Navy Civilian ATC[11]	Navy/Marines[12]			Air Force[13]			Coast Guard[14]		
Regulation Document	Army Regulation 40-501			Army: Army Regulation 40-501 Navy: NAVMED P-117, Chapter 15	NAVMED P-117, Chapter 15			Air Force Instruction 48-123			Commandant Instruction M6000.1D, Chapter 3		
Medical Requirements													
Regulation Section with Requirement Info	4-2 a.-b.	4-2. e. and 4-33. b.	4-2. d.	Army: 4-33. a. Navy: 15-95 (1)	15-63			6.1.1	6.46	6.45	3-G. 1.b.	3-G. 1. d.	3-G. 1. d.
Personnel who actively control the aircraft	Class 1 or 2, depending				Class I (subdivides into Medical Service Groups 1-3)			Class I, or II, (each with different subsections), depending,			Class 1		
Personnel who are not directly involved in controls	Class 3				Class II			Class II or III (each with different subsections), depending				Class 2	
ATC		Class 4		Army: Class IV OPM Standards Navy: Class IV OPM Standards and 15-95 of the P-117		Class III, and 15-95 of the P-117			Chap 5, Section 6I, and possibly 6K, depending				Class 2
UAS operators			Class 3				Class III, and 15-96 of the P-117			Chap 5, Section 6H	N/A	N/A	N/A

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10 Department of the Army, Sep 10, 2008, September 10, "Army Regulation 40-501, Medical Services, Standards of Medical Fitness," Headquarters, Department of the Army, Washington, D.C., Available: http://www.army.mil/usapa/epubs/pdf/r40_501.pdf (26 June 2010).

11 "Air Traffic Control Series," Available: http://www.opm.gov/qualifications/standards/IORs/gs2100/2152.htm (27 July 2010).

12 Department of the Navy, Aug 12, 2005, August 12, "Change 126, Manual of the Medical Department, U.S. Navy, NAVMED P-117, Chapter 15," Department of the Navy, Bureau of Medicine and Surgery, Washington, D.C., Available: http://www.med.navy.mil/directives/Documents/NAVMED%20P-117%20%28MANMED%29/MANMED%20CHANGE%20126%20with%20changes%20incorporated.pdf (26 July 2010).

13 Department of the Air Force, 2009, "Air Force Instruction 48-123, 24 September 2009, Incorporating Change 1, 1 June 2010, Aerospace Medicine, Medical Examinations and Standards," Department of the Air Force, Washington, D.C., Available: http://www.e-publishing.af.mil/shared/media/epubs/AFI48-123.pdf (21 June 2010).

14 United States Coast Guard, Sep 25, 2009, September 25, "Coast Guard Medical Manual, Commandant Instruction M6000.1D," Department of Homeland Security, United States Coast Guard, Washington, D.C., Available: http://www.uscg.mil/directives/cim/6000-6999/CIM_6000_1D.pdf (27 July 2010).

	Army[10]			Army/Navy Civilian ATC[11]	Navy/Marines[12]	Air Force[13]			Coast Guard[14]		
Insomnias											
Adjustment Insomnia	4-26. 2-30.*l*.	4-33.*b*.(9)	4-26. 2-30.*l*.	General Medical 3.**	15-84. 15-55 (16)	6.44.16.2 6.44.16.1.22	6.46	6.45.16.8	3-G.4.a. 3-D.28.l.	3-G.6.	3-G.9.
Psychophysiological Insomnia	4-26. 2-30.*l*.	4-33.*b* (9)	4-26. 2-30.*l*.	General Medical 3.**	15-84. 15-55 (16)	6.44.16.2 6.44.16.1.22	6.46	6.45.16.8	3-G.4.a. 3-D.28.l.	3-G.6.	3-G.9.
Paradoxical Insomnia	4-26. 2-30.*l*.	4-33.*b* (9)	4-26. 2-30.*l*.	General Medical 3.**	15-84. 15-55 (16)	6.44.16.2 6.44.16.1.22	6.46	6.45.16.8	3-G.4.a. 3-D.28.l.	3-G.6.	3-G.9.
Idiopathic Insomnia	4-26. 2-30.*l*.	4-33.*b* (9)	4-26. 2-30.*l*.	General Medical 3.**	15-84. 15-55 (16)	6.44.16.2 6.44.16.1.22	6.46	6.45.16.8	3-G.4.a. 3-D.28.l.	3-G.6.	3-G.9.
Insomnia Due to Mental Disorder	4-26. 2-30.*l*.	4-33.*b* (9)	4-26. 2-30.*l*.	General Medical 3.**	15-84. 15-55 (16)	6.44.16.2 6.44.16.1.22	6.46	6.45.16.8	3-G.4.a. 3-D.28.l.	3-G.6.	3-G.9.
	Army			Army/Navy Civilian ATC	Navy/Marines	Air Force			Coast Guard		
Inadequate Sleep Hygiene	4-26. 2-30.*l*.	4-33.*b* (9)	4-26. 2-30.*l*.	General Medical 3.**	15-84. 15-55 (16)	6.44.16.2 6.44.16.1.22	6.46	6.45.16.8	3-G.4.a. 3-D.28.l.	3-G.6.	3-G.9.
Insomnia Due to Drug or Substance	4-26. 2-30.*l*.	4-33.*b* (9)	4-26. 2-30.*l*.	General Medical 3.**	15-84. 15-55 (16)	6.44.16.2 6.44.16.1.22	6.46	6.45.16.8	3-G.4.a. 3-D.28.l.	3-G.6.	3-G.9.
Insomnia Due to Medical Condition	4-26. 2-30.*l*.	4-33.*b* (9)	4-26. 2-30.*l*.	General Medical 3.**	15-84. 15-55 (16)	6.44.16.2 6.44.16.1.22	6.46	6.45.16.8	3-G.4.a. 3-D.28.l.	3-G.6.	3-G.9.
Insomnia Not Due to Substance or Known Physiological Condition, Unspecified	4-26. 2-30.*l*.	4-33.*b* (9)	4-26. 2-30.*l*.	General Medical 3.**	15-84. 15-55 (16)	6.44.16.2 6.44.16.1.22	6.46	6.45.16.8	3-G.4.a. 3-D.28.l.	3-G.6.	3-G.9.
Physiological (Organic) Insomnia, Unspecified	4-26. 2-30.*l*.	4-33.*b* (9)	4-26. 2-30.*l*.	General Medical 3.**	15-84. 15-55 (16)	6.44.16.2 6.44.16.1.22	6.46	6.45.16.8	3-G.4.a. 3-D.28.l.	3-G.6.	3-G.9.
	Sleep Related Breathing Disorders										
	Central Sleep Apnea Syndromes										
Primary Central Sleep Apnea	4-26. 2-30.*l*.	4-33.*b* (9)	4-26. 2-30.*l*.	General Medical 3.**	15-84. 15-55 (16)	6.44.16.2 6.44.16.1.22	6.46	6.45.16.8	3-G.4.a. 3-D.28.l.	3-G.6.	3-G.9.
Central sleep Apnea Due to Cheyne Stokes Breathing Pattern	4-26. 2-30.*l*.	4-33.*b* (9)	4-26. 2-30.*l*.	General Medical 3.**	15-84. 15-55 (16)	6.44.16.2 6.44.16.1.22	6.46	6.45.16.8	3-G.4.a. 3-D.28.l.	3-G.6.	3-G.9.
Central Sleep Apnea Due to High-Altitude Periodic Breathing Pattern	**TRANSIENT DISORDER**										
	Obstructive Sleep Apnea Syndromes										
Obstructive Sleep Apnea, Adult	4-26. 2-30.*l*.	4-33.*b* (9)	4-26. 2-30.*l*.	General Medical 3.**	15-84. 15-55 (16)	6.44.16.2 6.44.16.1.22	6.46	6.45.16.8	3-G.4.a. 3-D.28.l.	3-G.6.	3-G.9.
	Sleep Related Hypoventilation/Hypoxemia Syndromes										
Sleep Related Nonobstructive Alveolar Hypoventilation, Idiopathic	4-26. 2-30.*l*.	4-33.*b* (9)	4-26. 2-30.*l*.	General Medical 3.**	15-84. 15-55 (16)	6.44.16.2 6.44.16.1.22	6.46	6.45.16.8	3-G.4.a. 3-D.28.l.	3-G.6.	3-G.9.
	Hypersomnias of Central Origin Not Due to a Circadian Rhythm Sleep Disorder, Sleep Related Breathing Disorder, or Other Cause of Disturbed Nocturnal Sleep										
Narcolepsy with Cataplexy	4-22. 2-26.*h*. ; 4-22.*e*.	4-33.*b* (4)	4-22. 2-26.*h*. ;4-22.*e*.	Neurological 2.	15-84 (11) 15-57 (16)	6.44.23.2. 6.44.23.1.9	6.46	6.45.16.8	3-G.4.a. 3-D.30.j.	3-G.6.	3-G.9.
Narcolepsy without Cataplexy	4-22. 2-26.*h*. ; 4-22.*e*.	4-33.*b* (4)	4-22. 2-26.*h*. ;4-22.*e*.	Neurological 2.	15-84 (11) 15-57 (16)	6.44.23.2. 6.44.23.1.9	6.46	6.45.16.8	3-G.4.a. 3-D.30.j.	3-G.6.	3-G.9.

	Army[10]			Army/Navy Civilian ATC[11]	Navy/Marines[12]	Air Force[13]			Coast Guard[14]		
Narcolepsy Due to Medical Condition	**4-22.** 2-26.*h.* ; 4-22.*e.*	**4-33.*b* (4)**	**4-22.** 2-26.*h.* ;4-22.*e.*	Neurological 2.	**15-84 (11)** 15-57 (16)	**6.44.23.2.** 6.44.23.1.9	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.30.j.	**3-G.6.**	**3-G.9.**
Narcolepsy, Unspecified	**4-22.** 2-26.*h.* ; 4-22.*e.*	**4-33.*b* (4)**	**4-22.** 2-26.*h.* ;4-22.*e.*	Neurological 2.	**15-84 (11)** 15-57 (16)	**6.44.23.2.** 6.44.23.1.9	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.30.j.	**3-G.6.**	**3-G.9.**
Recurrent Hypersomnia	**4-26.** 2-30.*l.*	**4-33.*b* (9)**	**4-26.** 2-30.*l.*	General Medical 3.**	**15-84.** 15-55 (16)	**6.44.16.2** 6.44.16.1.22	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.28.l.	**3-G.6.**	**3-G.9.**
Idiopathic Hypersomnia with Long Sleep Time	**4-26.** 2-30.*l.*	**4-33.*b* (9)**	**4-26.** 2-30.*l.*	General Medical 3.**	**15-84.** 15-55 (16)	**6.44.16.2** 6.44.16.1.22	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.28.l.	**3-G.6.**	**3-G.9.**
Idiopathic Hypersomnia without Long Sleep Time	**4-26.** 2-30.*l.*	**4-33.*b* (9)**	**4-26.** 2-30.*l.*	General Medical 3.**	**15-84.** 15-55 (16)	**6.44.16.2** 6.44.16.1.22	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.28.l.	**3-G.6.**	**3-G.9.**
Behaviorally Induced Insufficient Sleep Syndrome	**4-26.** 2-30.*l.*	**4-33.*b* (9)**	**4-26.** 2-30.*l.*	General Medical 3.**	**15-84.** 15-55 (16)	**6.44.16.2** 6.44.16.1.22	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.28.l.	**3-G.6.**	**3-G.9.**
Hypersomnia Due to Medical Condition	**4-26.** 2-30.*l.*	**4-33.*b* (9)**	**4-26.** 2-30.*l.*	General Medical 3.**	**15-84.** 15-55 (16)	**6.44.16.2** 6.44.16.1.22	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.28.l.	**3-G.6.**	**3-G.9.**
	Army			**Army/Navy Civilian ATC**	**Navy/Marines**	**Air Force**			**Coast Guard**		
Hypersomnia Due to Drug or Substance	**4-26.** 2-30.*l.*	**4-33.*b* (9)**	**4-26.** 2-30.*l.*	General Medical 3.**	**15-84.** 15-55 (16)	**6.44.16.2** 6.44.16.1.22	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.28.l.	**3-G.6.**	**3-G.9.**
Hypersomnia Not Due to Substance or Known Physiological Condition (Nonorganic Hypersomnia, NOS)	**4-26.** 2-30.*l.*	**4-33.*b* (9)**	**4-26.** 2-30.*l.*	General Medical 3.**	**15-84.** 15-55 (16)	**6.44.16.2** 6.44.16.1.22	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.28.l.	**3-G.6.**	**3-G.9.**
Physiological (Organic) Hypersomnia, Unspecified, (Organic Hypersomnia, NOS)	**4-26.** 2-30.*l.*	**4-33.*b* (9)**	**4-26.** 2-30.*l.*	General Medical 3.**	**15-84.** 15-55 (16)	**6.44.16.2** 6.44.16.1.22	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.28.l.	**3-G.6.**	**3-G.9.**
	Circadian Rhythm Sleep Disorders										
Delayed Sleep-Phase Disorder	**4-26.** 2-30.*l.*	**4-33.*b* (9)**	**4-26.** 2-30.*l.*	General Medical 3.**	**15-84.** 15-55 (16)	**6.44.16.2** 6.44.16.1.22	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.28.l.	**3-G.6.**	**3-G.9.**
Advanced Sleep-Phase Disorder	**4-26.** 2-30.*l.*	**4-33.*b* (9)**	**4-26.** 2-30.*l.*	General Medical 3.**	**15-84.** 15-55 (16)	**6.44.16.2** 6.44.16.1.22	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.28.l.	**3-G.6.**	**3-G.9.**
Irregular Sleep-Wake Rhythm	**4-26.** 2-30.*l.*	**4-33.*b* (9)**	**4-26.** 2-30.*l.*	General Medical 3.**	**15-84.** 15-55 (16)	**6.44.16.2** 6.44.16.1.22	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.28.l.	**3-G.6.**	**3-G.9.**
Nonentrained Type	**4-26.** 2-30.*l.*	**4-33.*b* (9)**	**4-26.** 2-30.*l.*	General Medical 3.**	**15-84.** 15-55 (16)	**6.44.16.2** 6.44.16.1.22	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.28.l.	**3-G.6.**	**3-G.9.**
Time Zone Change (Jet Lag) Syndrome	**TRANSIENT DISORDER**										
Shift Work Disorder	**4-26.** 2-30.*l.*	**4-33.*b* (9)**	**4-26.** 2-30.*l.*	General Medical 3.**	**15-84.** 15-55 (16)	**6.44.16.2** 6.44.16.1.22	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.28.l.	**3-G.6.**	**3-G.9.**
Circadian Rhythm Sleep Disorder Due to Medical Condition	**4-26.** 2-30.*l.*	**4-33.*b* (9)**	**4-26.** 2-30.*l.*	General Medical 3.**	**15-84.** 15-55 (16)	**6.44.16.2** 6.44.16.1.22	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.28.l.	**3-G.6.**	**3-G.9.**
Other Circadian Rhythm Sleep Disorder (Circadian Rhythm Disorder, NOS)	**4-26.** 2-30.*l.*	**4-33.*b* (9)**	**4-26.** 2-30.*l.*	General Medical 3.**	**15-84.** 15-55 (16)	**6.44.16.2** 6.44.16.1.22	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.28.l.	**3-G.6.**	**3-G.9.**
Other Circadian Rhythm Sleep Disorder Due to Drug or Substance	**4-26.** 2-30.*l.*	**4-33.*b* (9)**	**4-26.** 2-30.*l.*	General Medical 3.**	**15-84.** 15-55 (16)	**6.44.16.2** 6.44.16.1.22	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.28.l.	**3-G.6.**	**3-G.9.**
	Parasomnias										
	Other Parasomnias										

	Army[10]			Army/Navy Civilian ATC[11]	Navy/Marines[12]	Air Force[13]			Coast Guard[14]		
Sleep Related Eating Disorder	**4-26.** 2-30.*l.*	**4-33.*b* (9)**	**4-26.** 2-30.*l.*	General Medical 3.**	**15-84.** 15-55 (16)	**6.44.16.2** 6.44.16.1.22	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.28.l.	**3-G.6.**	**3-G.9.**
	Sleep Related Movement Disorders										
Restless Legs Syndrome	**4-26.** 2-30.*l.*	**4-33.*b* (9)**	**4-26.** 2-30.*l.*	General Medical 3.**	**15-84.** 15-55 (16)	**6.44.16.2** 6.44.16.1.22	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.28.l.	**3-G.6.**	**3-G.9.**
Periodic Limb Movement Disorder	**4-26.** 2-30.*l.*	**4-33.*b* (9)**	**4-26.** 2-30.*l.*	General Medical 3.**	**15-84.** 15-55 (16)	**6.44.16.2** 6.44.16.1.22	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.28.l.	**3-G.6.**	**3-G.9.**
Sleep Related Leg Cramps	**4-26.** 2-30.*l.*	**4-33.*b* (9)**	**4-26.** 2-30.*l.*	General Medical 3.**	**15-84.** 15-55 (16)	**6.44.16.2** 6.44.16.1.22	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.28.l.	**3-G.6.**	**3-G.9.**
Sleep Related Bruxism	**4-26.** 2-30.*l.*	**4-33.*b* (9)**	**4-26.** 2-30.*l.*	General Medical 3.**	**15-84.** 15-55 (16)	**6.44.16.2** 6.44.16.1.22	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.28.l.	**3-G.6.**	**3-G.9.**
Sleep Related Rhythmic Movement Disorder	**4-26.** 2-30.*l.*	**4-33.*b* (9)**	**4-26.** 2-30.*l.*	General Medical 3.**	**15-84.** 15-55 (16)	**6.44.16.2** 6.44.16.1.22	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.28.l.	**3-G.6.**	**3-G.9.**
Sleep Related Movement Disorder, Unspecified	**4-26.** 2-30.*l.*	**4-33.*b* (9)**	**4-26.** 2-30.*l.*	General Medical 3.**	**15-84.** 15-55 (16)	**6.44.16.2** 6.44.16.1.22	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.28.l.	**3-G.6.**	**3-G.9.**
	Army			**Army/Navy Civilian ATC**	**Navy/Marines**	**Air Force**			**Coast Guard**		
Sleep Related Movement Disorder Due to Drug or Substance	**4-26.** 2-30.*l.*	**4-33.*b* (9)**	**4-26.** 2-30.*l.*	General Medical 3.**	**15-84.** 15-55 (16)	**6.44.16.2** 6.44.16.1.22	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.28.l.	**3-G.6.**	**3-G.9.**
Sleep Related Movement Disorder Due to Medical Condition	**4-26.** 2-30.*l.*	**4-33.*b* (9)**	**4-26.** 2-30.*l.*	General Medical 3.**	**15-84.** 15-55 (16)	**6.44.16.2** 6.44.16.1.22	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.28.l.	**3-G.6.**	**3-G.9.**
	Isolated Symptoms, Apparently Normal Variants, and Unresolved Issues										
Long Sleeper	+	+	+	+	+	+	+	+	+	+	+
Excessive Fragmentary Myoclonus	+	+	+	+	+	+	+	+	+	+	+
	Other Sleep Disorders										
Environmental Sleep Disorder	**4-26.** 2-30.*l.*	**4-33.*b* (9)**	**4-26.** 2-30.*l.*	General Medical 3.**	**15-84.** 15-55 (16)	**6.44.16.2** 6.44.16.1.22	**6.46**	6.45.16.8	**3-G.4.a.** 3-D.28.l.	**3-G.6.**	**3-G.9.**

+: insufficient information to determine if DQ
**: would be determined during the course of the evaluation

For the Army ATC, the regulations refer back to the bolded regulations in the previous column which refer to the un-bolded regulations.
For the Navy/Marines the bolded regulations refer back to the un-bolded regulations.
For the Air Force (AF) ATC, the regulations refer back to the bolded regulations in the previous column which refer to the un-bolded regulations.
For the Coast Guard (CG) Class2 and ATC, the regulations refer back to the bolded regulations in the first column which refer to the un-bolded regulations.

Army, Navy, and Air Force have guidance on waivers. Army: OSA is disqualifying for Class 1A/1W initial applicants unless it has been resolved with surgery and a PSG confirms this. For initial applicants for Classes 2F, 3, and 4, case-by-case waivers can be granted. For all classes of rated aviation personnel OSA is disqualifying, but for Classes 2, 2F, 3 and 4, case-by-case waivers may be granted if the OSA is resolved with CPAP, weight loss, surgery, or a dental device with a confirming PSG. Specific information required for the waiver submission as well as follow-up, and treatment information is available in the Aeromedical Policy Letters, Pulmonary Disease Waivers section, on page Pulmonary—5 (Bernstein, 2003). For other sleep disorders, if they cannot be resolved short-term with either medical or surgical agents, they will not be waivered. Transient sleep disorders that are induced by obesity, a life crisis, or various medical conditions can be waivered after recovery. RLS can be waivered after the underlying cause is cured and the RLS is resolved. Waivers for Hypersomnias are not likely, see the Aeromedical Policy letters, Psychiatric Waivers section, page Psychiatric—26 for additional information (Bernstein, 1997).

Navy: a history of sleep disorders is disqualifying, "[b]ecause of the persistent nature and impact on psychomotor and cognitive performance" (Naval Operational Medical Institute, Naval Aerospace Medical Institute, 2009, p. 174). However, disorders that have been successfully treated may be considered for a waiver and information required for consideration of a waiver includes a consultation with a sleep specialist, a PSG, vigilance testing, and a psychiatric evaluation. Additionally, information regarding specific disorders is included in the guide. For OSA, CPAP is not allowed for aviation applicants but may be waivered in designated aviation personnel. If OSA is resolved with uvulopharyngopalatoplasty and post-surgical testing indicates no EDS, a waiver may be considered. Transient insomnia complaints do not need a waiver, but if persistent, testing must be done to determine the diagnosis and the disorder treated before a waiver will be considered. Idiopathic hypersomnia, narcolepsy, and PLMD are disqualifying and are not considered for waivers. RLS is not considered for waivers in applicants, but may be considered for waivers in designated aviators. The underlying medical condition of secondary RLS must be identified and treated before a waiver will be considered. Also, many of the medications used to treat RLS are not approved. Circadian Rhythm Sleep Disorders, Advanced Phase Type, Delayed Phase Type, Irregular Sleep Wake Type and Free-Running Type are disqualifying, but if they can be successful treated, which the waiver guide stresses is only possible in a very small percentage of patients, a waiver may be considered. Jet Lag Type is transient and does not need a waiver, but personnel may be grounded until their circadian rhythm resynchronizes. If aviation personnel are bothered enough by Shift Work Type to seek medical attention, it is disqualifying and a waiver is not recommended. Sleep disorders that are related to medical conditions will be treated in accordance to the medical condition, which generally resolves the sleep disturbances (Naval Operational Medical Institute, Naval Aerospace Medical Institute, 2009).

Air Force (Class II and III personnel): Mild to moderate OSA can be waivered if the service member has satisfactory results on neuropsychological tests and mild OSA is waiver able for Class II flying personnel. Moderate to severe OSA may be waivered if an oral device or surgery resolves the service member's OSA. A PSG and neuropsychological testing will be done by Aeromedical Consultation Services (ACS) for any aviator that is diagnosed with a sleep disorder before he or she may be considered for return to flight duty. Additionally, it is stated that narcolepsy is disqualifying and will not be considered for waivers. Specific information regarding the protocol for sleep disorders and waivers can be found on pages 494-497 in the Sleep Disorders section of the Air Force Waiver Guide (Aeromedical Consultation Service, United States Air Force, 2007).

Publicly available information regarding sleep disorder waivers in the Coast Guard and class I of the Air Force could not be found.

I.10.3 Gaps

The four questions Dr. Pack identified in 1995 still require answering and are gaps. That is, should sleep apnea (and other sleep disorder) screening be an employment condition? How will the screening be done cost effectively? If a professional is diagnosed with a sleep disorder should he or she be paid disability? If an accident results from an untreated sleep disorder, who will be held responsible? The employer or the employee?

In addition to these questions, there are also other pertinent gaps. Protocols for screening for disorders must be developed. A question eliciting information about sleep disorder history or symptoms would be a simple addition to the history forms for airmen and ATC medical exams. Questions about BMI and neck circumference could also be added to identify those at risk for OSA, and an ESS could easily be incorporated into the exam to identify those at risk for EDS. To note, it would have to be determined what scores the aviation industry will consider at-risk on the ESS. In regards to OSA, the AHI cut-off for the definition of OSA needs to be decided upon, and before this can be decided upon, an accepted definition of hypopnea MUST be settled on for the aviation industry. What treatments will be acceptable for OSA and other disorders also must be determined. For those identified as at risk EDS, what steps will be taken next must be determined. Should all of the ATCSs and airmen identified as at risk for EDS immediately have a PSG, MWT and/or MSLT? For those identified as at risk for OSA, should they first use an at-home single-flow channel, or should everyone who has a history pointing to OSA immediately have a PSG? The aviation industry might consider developing something similar to what the Joint Task Force recommended for OSA in the commercial driving industry. That is, a guide for the screening, diagnosis, treatment, compliance and effectiveness to/of therapy, guidelines for return to work, and follow-up requirements for ATCSs/airmen with OSA should be developed.

Appendix J Acronyms List

Acronym	Definition
AASI	AME Assisted Special Issuance
AASM	American Academy of Sleep Medicine
ABSITE	American Board of Surgery In-Training Examination
AC	Advisory Circular
ACRP	Airport Cooperative Research Program
ACS	Aeromedical Consultation Services
AESOP	Aircrew Evaluation Sustained Operations Performance
AF	Air Force
AFI	AWVT (Auditory Working-Memory Vigilance Task) Fatigue Index
AFRL	Air Force Research Laboratory
AFSS	Automated Flight Service Station
AFTIL	Airways Facilities Tower Integration Laboratory
AGARD	Advisory Group for Aerospace Research and Development
AHI	Apnea-Hypopnea Index
AIAA	American Institute of Aeronautics and Astronautics
AIM	Assessing the Impact of Mental Workload
AL	Annual Leave
ALPA	Air Line Pilots Association
AM	Amplitude Modulation
AMCD	Aerospace Medical Certification Division
AME	Aviation Medical Examiner
ANAM	Automated Neuropsychological Assessment Metric
ANSP	Air Navigation Service Provider
APAP	Autotitrating Positive Airway Pressure
APTS	Automated Performance Test System
ARC	Aviation Rulemaking Committee

Acronym	**Definition**
ARTCC	Air Route Traffic Control Center
ASAA	American Sleep Apnea Association
ASDE-X	Airport Surface Detection Equipment, Model X
ASP	Circadian Rhythm Sleep Disorder, Advanced Sleep Phase Type
ASR	Air Safety Report
ATC	Air Traffic Control
ATCs	Air Traffic Controllers
ATCS	Air Traffic Control Specialist
ATI	Air Transport International
ATIO	Aviation Technology Integration and Operations
ATM	Air Traffic Management
ATS	Air Traffic Service
ATSAT	Air Traffic Scenarios Test
ATWIT	Air Traffic Workload Input Technique
AUVSI	Association for Unmanned Vehicle Systems International
AWACS	Airborne Warning and Control System
AWVT	Auditory Working-Memory Vigilance Task
BA	Baseline Automation
BAC	Blood Alcohol Concentration
BAT	Basic Assessment Tool
BFI	Brief Fatigue Inventory
BMI	Body Mass Index
BNSF	Burlington Northern Santa Fe
BPAP	Bi-level Positive Airway Pressure
CAA	Civil Aviation Authority
CAASD	Center for Advanced Aviation System Development
CAMI	Civil Aerospace Medical Institute
CAP	Civil Aviation Publication
CAR	Civil Aviation Rule

Acronym	Definition
CAS	Circadian Alertness Simulator
CASA	Civil Aviation Safety Authority
CBT	Cognitive Behavioral Therapy
CCI	Competitive Capabilities International
CD	Compact disc
CEO	Chief Executive Officer
CFR	Code of Federal Regulations
CFS	Chalder Fatigue Scale
CG	Coast Guard
CHI	Computer Human Interface
CIS	Checklist Individual Strength
CISCON	Checklist Individual Strength – Concentration Subscale
CPAP	Continuous Positive Airway Pressure
CPC	Certified Professional Controller
CSA	Central Sleep Apnea
CSB	Cheyne Stokes Breathing pattern
D.C.	District of Columbia
DASC	Digital Avionics Systems Conference
DBRITE	Digital Bright Radar Indicator Tower Equipment
DFDR	Digital Flight Data Recorder
DGAC	Direction générale de l'Aviation civile (translated: Directorate General of Civil Aviation)
DLR	German Aerospace Center
DoD	Department of Defense
DOT	Department of Transportation
DQ	Disqualifying
DSP	Circadian Rhythm Sleep Disorder, Delayed Sleep Phase Type
DSS	Daytime Sleepiness Scale
DSSQ	Dundee Stress State Questionnaire
DTIC	Defense Technical Information Center

Acronym	Definition
DYSIM	Dynamic Simulator
EA	Enhanced Automation
EASA	European Aviation Safety Agency
ECG	Electrocardiogram
EDS	Excessive Daytime Sleepiness
EE	Emotional Exhaustion
EEG	Electroencephalogram
EF	Energy and Fatigue
EF-WHOQOL	World Health Organization Quality Of Life Assessment Energy And Fatigue Subscale
EMG	Electromyography
ENRI	Electronic Navigation Research Institute
EOG	Electrooculogram
ERA	En Route Analysis
ERAM	En Route Automation Modernization
ESS	Epworth Sleepiness Scale
EU	European Union
EUROCONTROL	European Organisation for the Safety of Air Navigation
FAA	Federal Aviation Administration
FAAO	Federal Aviation Administration Order
FACES	Fatigue, Anergy, Consciousness, Energized, and Sleepiness
FACT	Functional Assessment of Cancer Therapy
FAI	Fatigue Assessment Inventory
FAID	Fatigue Audit InterDyne
FAS	Fatigue Assessment Scale
FAST	Fatigue Avoidance Scheduling Tool
FDM	Flight Data Monitoring
FFD	Fitness-for-Duty
FIS	Fatigue Impact Scale
FIT	Fatigue Index Tool

Acronym	Definition
FORAS	Flight Operations Risk Assessment System
FOSQ	Functional Outcomes of Sleep Questionnaire
FPL	Full Performance Level
FRA	Federal Railroad Administration
FRMS	Fatigue Risk Management System
FS	Fatigue Scale
FSF	Flight Safety Foundation
FSI	Fatigue Symptom Inventory
FSS	Fatigue Severity Scale
FSS	Flight Service Station
GFS	General Fatigue Scale
GHB	Gamma Hydroxybutyrate
GS	General Schedule
HITL	Human-in-the-Loop
HOS	Hours of Service
HPA	High Performance Airspace
HR	Heart Rate
HRV	Heart Rate Variability
HUF	Terre Haute sector
IAG	Issue Assessment Group
IASS	International Air Safety Seminar
IATA	International Air Transport Association
IBR	Institutes for Behavior Resources, Inc.
ICAO	International Civil Aviation Organization
ICSD-2	International Classification of Sleep Disorders, Second Edition
IEEE	Institute of Electrical and Electronic Engineers
IFA	International Federation of Airworthiness
IFR	Instrument Flight Rules
IL	Illinois

Acronym	**Definition**
INM	Interactive Neurobehavioral Model
IPM	Institute for Psychosocial Medicine
ISA	Instantaneous Self Assessment
ITS	Intelligent Tutoring System
KA	Knowledge and Ability
KS	Kansas
KSS	Karolinska Sleepiness Scale
LCT	Letter Cancellation Task
LED	Light Emitting Diodes
MA	Manned Aircraft
MBI	Maslach Burnout Inventory
MBI-EE	Maslach Burnout Inventory - Emotional Exhaustion Subscale
MFI	Multidimensional Fatigue Inventory
MITRE	The MITRE Corporation
MLC	Multiple Landing Clearances
MO	Missouri
MP	MITRE Product
MRD	Mandibular Repositioning Device
MSL	Mean Sea Level
MSLT	Multiple Sleep Latency Test
MTR	MITRE Technical Report
MTV	Mount Vernon
MWT	Maintenance of Wakefulness Test
N/A	Not Applicable
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASA-TLX	NASA Task Load Index
NATCA	National Air Traffic Controllers Association
NATO	North Atlantic Treaty Organization

Acronym	**Definition**
NAVMED	Naval Medical Command
NCSDR	National Center on Sleep Disorders Research
NEI	Nuclear Energy Institute
NINDS	National Institute of Neurological Disorders and Stroke
NIOSH	National Institute for Occupational Safety and Health
NJ	New Jersey
NOS	Not Otherwise Specified
NPRM	Notice of Proposed Rulemaking
NREM	Non Rapid Eye Movement
NSW	New South Wales
NTIS	National Technical Information Service
NTSB	National Transportation Safety Board
NV	Nevada
NY	New York
NZ	New Zealand
OA	Oral Appliance
OE	Operational Errors
OEDS	Operational Error/Deviation System
OJT	On-the-Job Training
OK	Oklahoma
OPM	Office of Personnel Management
ORD	Chicago O'Hare International Airport
OSA	Obstructive Sleep Apnea
OSHA	Occupational Safety and Health Administration
PAB	Performance Assessment Battery
PANAS	Positive Negative Affect Schedule
PAP	Positive Airway Pressure
P-ATM	Performance-Based Air Traffic Management
PCT	Potomac TRACON

Acronym	Definition
PFS	Piper Fatigue Scale
PLMD	Periodic Limb Movement Disorder
PM	Portable Monitoring
POMS	Profile of Mood States
PSG	Polysomnogram
PSWM	Prior Sleep Wake Model
PTT	Position to Traffic
PVT	Psychomotor Vigilance Test
R&D	Research and Development
RAPCON	Radar Approach Control
RDI	Respiratory Distress Index
RDO	Regular Day Off
REM	Rapid Eye Movement
RFS	Regional Flight Surgeon
RLS	Restless Leg Syndrome
RMS	Root Mean Square
RNAV	Area Navigation
RNP	Required Navigation Performance
R-SAT	Rapidly Deployable Stand Alone Air Traffic Control Trainer
RSME	Rating Scale Mental Effort
SA	Situation Awareness
SAFE	System for Aircrew Fatigue Evaluation
SAFTE	Sleep, Activity, Fatigue, and Task Effectiveness
SAGAT	Situation Awareness Global Assessment Technique
SAM	School of Aerospace Medicine
SART	Situation Awareness Rating Technique
SASHA	Situation Awareness for SHAPE
SATI	SHAPE Automation Trust Index
SAVANT	Situation Awareness Verification and Analysis Tool

Acronym	**Definition**
SCL	Skin Conductance Level
SEIFR	Single Engine Instrument Flight Rules
SFRA	Special Flight Rules Area
SMS	Safety Management System
SNT	Staffed NextGen Tower
SPAM	Situation Present Assessment Method
SPE	Society of Petroleum Engineers
SRBD	Sleep Related Breathing Disorder
SRED	Sleep Related Eating Disorder
SSI	Standard Shiftwork Index
SSRI	Selective Serotonin Reuptake Inhibitor
SSS	Stanford Sleepiness Scale
STINET	Scientific and Technical Information Network
STMC	Supervisory Traffic Management Coordinator
STPI	State Trait Personality Inventory
SWAI	Sleep Wake Activity Inventory
SWP	Sleep/Wake Predictor
SWS	Slow Wave Sleep
TCCA	Transport Canada Civil Aviation
TCRP	Transit Cooperative Research Program
TDC	Transportation Development Centre
TFM	Traffic Flow Management
TITAN	Team and Individual Threat Assessment Task
TLI	Traffic Load Index
TMC	Traffic Management Coordinators
TMI	Traffic Management Initiatives
TRACON	Terminal Radar Approach Control
TRD	Tongue Retaining Device
TSFS	Toronto Sleepiness and Fatigue Scale

Acronym	Definition
TX	Texas
U.S.	United States
U.S.C.	United States Code
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UAV STE	Unmanned Aerial Vehicles Synthetic Task Environment
UK	United Kingdom
URET	User Request Evaluation Tool
USA	United States of America
USAF	United States Air Force
USDOT	United States Department of Transportation
USNRC	U.S. Nuclear Regulatory Commission
VA	Virginia
VAMPIRE	Visual and Manned Performance in Illumination Reduced Environments
VAS-F	Visual Analog Fatigue Scale
WA	Washington
K-WAIS	Korean Wechsler Adult Intelligence Scale
WAM	Wrist Activity Monitors
WHOQOL	World Health Organization Quality Of Life Assessment
ZID	Indianapolis Air Route Traffic Control Center