Defence Research and Development Canada
Recherche et développement pour la défense Canada

DEFENCE R&D DÉFENSE

Consideration of 5 Canadian Forces Fire Fighter Shift Schedules

Michel A. Paul
DRDC Toronto

James C. Miller
USAF Research Laboratory

Defence R&D Canada – Toronto
Technical Report
DRDC Toronto TR 2005-227
October 2005

Canada

Consideration of 5 Canadian Forces Fire Fighter Shift Schedules

Michel A. Paul
DRDC Toronto

James C. Miller
USAF Research Laboratory

Defence R&D Canada – Toronto

Technical Report
DRDC Toronto TR 2005-227
October 2005

First Author

Michel A. Paul, M.Sc.

Approved by

Dr. Pang Shek,

H/Operational Medicine Section

Approved for release by

KM Sutton

Chair, Document Review and Library Committee

James C. Miller is a Senior Research Physiologist with the US Air Force Research Laboratory at Brooks City Base, San Antonio, Texas, USA

Abstract

INTRODUCTION. DRDC Toronto received a BL-2 tasking from the CF Fire Marshall to assess 5 different fire fighter schedules, along with a request for DRDC Toronto to recommend which of the 5 schedules is “optimum”. Any skilled performance or safety critical performance should occur when personnel are operating at their best. Best performance is normally considered to mean between 100% and 90% cognitive effectiveness. When performance declines to 90%, it is time to cease skilled operations and get some rest. METHODS. The duty times, and the sleep times for each of the 5 shift schedules were used as inputs to the FAST (Fatigue Avoidance Scheduling Tool) Program (a modelling program which calculates cognitive effectiveness as a function of duty and rest cycles). Each of the 5 shift schedules was modelled in 2 ways; 1) first with no fires/emergencies, and 2) subsequently with nocturnal alarms occurring at 0200 hrs and the fire fighters returning to the fire hall at 0500 hrs. RESULTS. With no fires/emergencies all 5 schedules resulted in similar small impacts on cognitive effectiveness (from 84% to 88%) just before retiring for bed around 2300 hrs. The nocturnal alarms caused some attrition of cognitive effectiveness on the subsequent day which ranged from 82% to 79%, and after several days (for schedules 1, 2, and 3) cognitive effectiveness declined further to the 72% to 68% range. Schedules 4 and 5 did not involve successive duty days. During the first duty night, an alarm on either schedule 4 or schedule 5 resulted in similar impacts on cognitive effectiveness as schedules 1 to 3. However, since there was no duty the subsequent day, cognitive effectiveness recovered somewhat the next day. In the case of schedule 4, since the 24-hr shift was followed by 72 hours off, cognitive effectiveness was fully recovered before the next shift. In the case of schedule 5, because the 2nd duty period occurred within 24 hrs of the 1st duty period, recovery was not complete and cognitive effectiveness was somewhat lower in the 2nd duty period. CONCLUSIONS. All five schedules were predicted to sustain cognitive performance as long as there are no alarms during the night. If night-time alarms occur, impact on cognitive effectiveness occurs similarly across all schedules with recovery of cognitive effectiveness taking up to 48 hrs. However, since schedule 4 provides for 3 days of rest after each 24-hr work period, cognitive performance is fully restored before the next duty period. RECOMMENDATIONS. With respect to sustaining cognitive performance in the face of nocturnal alarms, clearly schedule 4 is the best schedule and schedule 5 is the second best.

Résumé

INTRODUCTION. RDDC Toronto a reçu du Service des incendies des Forces canadiennes (SIFC) une tâche du SA 2 visant l'évaluation de cinq horaires de travail différents pour les pompiers, ainsi qu'une demande de recommandation quant à l'horaire « optimum » parmi les cinq. Toute tâche spécialisée ou essentielle à la sécurité devrait être effectuée lorsque le personnel est en pleine forme. On estime habituellement que le meilleur rendement est fourni lorsque l'efficacité cognitive se situe entre 100 p. 100 et 90 p. 100. Lorsque le rendement chute à 90 p. 100, il est temps de cesser les opérations spécialisées et de prendre du repos. MÉTHODES. Les périodes de service et les périodes de sommeil prévues dans chacun des cinq horaires des quarts de travail ont été entrées comme données dans le programme FAST (Fatigue Avoidance Scheduling Tool – outil d'établissement d'horaires visant à éviter la fatigue) (programme de modélisation qui calcule l'efficacité cognitive en fonction des cycles de service et de repos). Chacun des cinq horaires des quarts de travail a été modélisé de deux façons : 1) premièrement, en ne prévoyant aucun incendie/aucune urgence, et 2) deuxièmement, en prévoyant des alertes de nuit survenant à 02 h 00 et un retour des pompiers à la caserne à 05 h 00. RÉSULTATS. Dans le cas des modèles ne prévoyant aucun incendie/aucune urgence, les cinq horaires ont eu des répercussions minimes similaires sur l'efficacité cognitive (celle-ci se situant entre 84 p. 100 et 88 p. 100) juste avant que les pompiers aillent se coucher vers 23 h 00. Pour leur part, les alertes nocturnes ont entraîné une baisse de l'efficacité cognitive le jour suivant, cette dernière allant de 82 p. 100 à 79 p. 100, et après plusieurs jours (dans le cas des horaires 1, 2 et 3), l'efficacité cognitive a encore diminué pour se situer entre 72 p. 100 et 68 p. 100. Les horaires 4 et 5 ne comportaient pas de jours de service successifs. Au cours de la première nuit de service, une alerte déclarée pendant le déroulement de l'horaire 4 ou 5 a eu des répercussions sur l'efficacité cognitive semblables à celles constatées dans le cadre des horaires 1 à 3. Cependant, comme aucune période de service n'était prévue le lendemain, l'efficacité cognitive a pu être rétablie en partie pendant cette journée. Dans le cas de l'horaire 4, étant donné que le quart de travail de 24 heures était suivi de 72 heures de congé, l'efficacité cognitive a été entièrement rétablie avant le quart de travail suivant. Dans le cas de l'horaire 5, comme la deuxième période de service est survenue dans les 24 heures suivant la première période de service, la récupération n'a pas été complète, et l'efficacité cognitive était quelque peu inférieure au cours de la deuxième période de service. CONCLUSIONS. Selon les prévisions, les cinq horaires permettraient de maintenir le rendement cognitif tant qu'il n'y a pas d'alerte au cours de la nuit. Si une alerte nocturne se produit, elle entraîne les mêmes répercussions sur l'efficacité cognitive quel que soit l'horaire, la récupération de l'efficacité cognitive pouvant exiger jusqu'à 48 heures. Cependant, comme l'horaire 4 prévoit trois jours de repos après chaque période de travail de 24 heures, le rendement cognitif est complètement rétabli avant la période de service suivante. RECOMMANDATIONS. En ce qui concerne le maintien du rendement cognitif en cas d'alertes nocturnes, il est clair que le meilleur horaire est l'horaire 4, suivi de l'horaire 5.

Executive summary

INTRODUCTION. DRDC Toronto received a Business Line-2 tasking from the CF Fire Marshall to assess 5 different fire fighter schedules, along with a request for DRDC Toronto to recommend which of the 5 schedules is "optimum". Any skilled performance or safety critical performance should occur when personnel are operating at their best. Best performance is normally considered to mean between 100% and 90% cognitive effectiveness. When performance declines to 90%, it is time to cease skilled operations and get some rest. The duty times for each of the 5 shift schedules, along with the normal shift sleep times (provided by the CF Fire Marshall) were used as inputs to the FAST*TM* (Fatigue Avoidance Scheduling Tool) Program. FAST*TM* is a modelling program which calculates cognitive effectiveness as a function of duty and rest cycles). Each of the 5 shift schedules was modelled in 2 ways; 1) first with no fires/emergencies, and 2) subsequently with nocturnal alarms occurring at 0200 hrs and the fire fighters returning to the fire hall at 0500 hrs. RESULTS. With no fires/emergencies all 5 schedules resulted in similar small impacts on cognitive effectiveness just before retiring for bed around 2300 hrs. However, the nocturnal alarms caused some additional attrition of cognitive effectiveness on the subsequent day, and after several days (for schedules 1, 2, and 3) cognitive effectiveness declined further. Schedules 4 and 5 did not involve successive duty days. During the first duty night, an alarm on either schedule 4 or schedule 5 resulted in similar impacts on cognitive effectiveness as schedules 1 to 3. However, since there was no duty the subsequent day, cognitive effectiveness recovered somewhat the next day but would take an additional day to fully recover. In the case of schedule 4, since the 24-hr shift was followed by 72 hours off, cognitive effectiveness was fully recovered before the next shift. In the case of schedule 5, because the 2nd duty period occurred within 24 hrs of the 1st duty period, recovery was not complete and cognitive effectiveness was somewhat lower in the 2nd duty period. SIGNIFICANCE OF RESULTS. All five schedules were predicted to sustain cognitive performance as long as there are no alarms during the night. If night-time alarms occur, impact on cognitive effectiveness occurs similarly across all schedules with recovery of cognitive effectiveness taking up to 48 hrs. However, since schedule 4 provides for 3 days of rest after each 24-hr work period, cognitive performance is fully restored before the next duty period. CONCLUSION. With respect to sustaining cognitive performance in the face of nocturnal alarms, clearly schedule 4 is the best schedule and schedule 5 is the second best.

Paul, MA, Miller, JC. 2005. Consideration of 5 Canadian Forces Fire Fighter Shift Schedules. DRDC Toronto TR 2005-227 Defence R & D Canada - Toronto.

Sommaire

INTRODUCTION. RDDC Toronto a reçu du Service des incendies des Forces canadiennes (SIFC) une tâche du SA 2 visant l'évaluation de cinq horaires de travail différents pour les pompiers, ainsi qu'une demande de recommandation quant à l'horaire « optimum » parmi les cinq. Toute tâche spécialisée ou essentielle à la sécurité devrait être effectuée lorsque le personnel est en pleine forme. On estime habituellement que le meilleur rendement est fourni lorsque l'efficacité cognitive se situe entre 100 p. 100 et 90 p. 100. Lorsque le rendement chute à 90 p. 100, il est temps de cesser les opérations spécialisées et de prendre du repos. Les périodes de service prévues dans chacun des cinq horaires des quarts de travail , ainsi que les périodes de sommeil habituelles (indiquées par le SIFC) ont été entrées comme données dans le programme FAST^{TM} (Fatigue Avoidance Scheduling Tool – outil d'établissement d'horaires visant à éviter la fatigue). Le FAST^{TM} est un programme de modélisation qui calcule l'efficacité cognitive en fonction des cycles de service et de repos. Chacun des cinq horaires des quarts de travail a été modélisé de deux façons : 1) premièrement, en ne prévoyant aucun incendie/aucune urgence, et 2) deuxièmement, en prévoyant des alertes de nuit survenant à 02 h 00 et un retour des pompiers à la caserne à 05 h 00. RÉSULTATS. Dans le cas des modèles ne prévoyant aucun incendie/aucune urgence, les cinq horaires ont eu des répercussions minimes similaires sur l'efficacité cognitive juste avant que les pompiers aillent se coucher vers 23 h 00. Cependant, les alertes nocturnes ont entraîné une baisse supplémentaire de l'efficacité cognitive le jour suivant et, après plusieurs jours (dans le cas des horaires 1, 2 et 3), l'efficacité cognitive a encore diminué. Les horaires 4 et 5 ne comportaient pas de jours de service successifs. Au cours de la première nuit de service, une alerte déclarée pendant le déroulement de l'horaire 4 ou 5 a eu des répercussions sur l'efficacité cognitive semblables à celles constatées dans le cadre des horaires 1 à 3. Cependant, comme aucune période de service n'était prévue le lendemain, l'efficacité cognitive a pu être rétablie en partie, mais une autre journée serait nécessaire pour une récupération complète. Dans le cas de l'horaire 4, étant donné que le quart de travail de 24 heures était suivi de 72 heures de congé, l'efficacité cognitive a été entièrement rétablie avant le quart de travail suivant. Dans le cas de l'horaire 5, comme la deuxième période de service est survenue dans les 24 heures suivant la première période de service, la récupération n'a pas été complète, et l'efficacité cognitive était quelque peu inférieure au cours de la deuxième période de service. SIGNIFICATION DES RÉSULTATS. Selon les prévisions, les cinq horaires permettraient de maintenir le rendement cognitif tant qu'il n'y a pas d'alerte au cours de la nuit. Si une alerte nocturne se produit, elle entraîne les mêmes répercussions sur l'efficacité cognitive quel que soit l'horaire, la récupération de l'efficacité cognitive pouvant exiger jusqu'à 48 heures. Cependant, comme l'horaire 4 prévoit trois jours de repos après chaque période de travail de 24 heures, le rendement cognitif est complètement rétabli avant la période de service suivante. CONCLUSION. En ce qui concerne le maintien du rendement cognitif en cas d'alertes nocturnes, il est clair que le meilleur horaire est l'horaire 4, suivi de l'horaire 5.

Paul, MA, Miller, JC. 2005. Consideration of 5 Canadian Forces Fire Fighter Shift Schedules. DRDC Toronto TR 2005-227 Defence R & D Canada - Toronto.

Table of contents

List of figures

List of table

Introduction

DRDC Toronto received a BL-2 tasking from the CF Fire Marshall to assess 5 different fire fighter schedules, along with a request for DRDC Toronto to recommend which of the 5 schedules is "optimum".

One issue we raised when assessing these 5 schedules was the acceptability of a 24-hour shift length. There is widespread use of 24-h shifts in fire houses in Canada and the United States. Thus, obviously, many operations do view the 24-h shift length as being acceptable. To consider this issue in depth, one must also consider how many crews are employed to cover the 24-hour-per-day, 7-day-per-week (24/7) fire protection demand. The number of crews determines the average work-week length. For 3 crews, the average workweek length is (168 h per week / 3 crews =) 56 hours per crew per week; for 4 crews, it is 42 hours per week.

One can use 12-h or 24-h shifts with either 3 or 4 crews, but 12-h shifts with 3 crews provides too little time off: firefighters would probably never have more than 2 contiguous days off, the first of which follows a night shift. Local governments noted the obvious long ago: it is cheaper to employ 3 crews than 4. However, with 3 crews, they also probably found that it was essential to use work compression (i.e., the 24-h shift instead of the 12-h shift) to allow acceptable amounts of contiguous time off. They probably learned this because of personnel attrition caused by firefighter dissatisfaction with unacceptably-short periods of time-off. This may be the historical context within which 24-hour shifts came to be associated with urban firefighting. It was an acceptable and efficient method for employing only 3 crews.

Subsequently, because of rules and expectations generated by such actions as the US Fair Labor Standards Act, many firefighting agencies moved to 4-crew solutions to the 24/7 protection demand to get the average work-week length down from 56 to 42 hours. The CF Fire Marshall works with a 4-crew solution. As with workers in nearly all shiftwork systems, some of the Fire Marshall's firefighters may be pressing for work compression (24-h shifts) to gain longer contiguous periods of time off. Since 24-h shift lengths are used widely in urban firefighting, they are viewed by firefighters as an "acceptable" approach to work compression.

Any skilled performance or safety critical performance should occur when personnel are operating at their best. Best performance is normally considered to mean between 100% and 90% cognitive effectiveness. When performance declines to 90%, it is time to cease skilled operations and get some rest.

Fatigue Avoidance Scheduling Tool (FAST™; Appendix C (2), is a performance modelling software program which uses daily work schedule and daily sleep as inputs to determine the resultant cognitive effectiveness of the individuals engaged in such work/rest schedules. FAST™ simulations were used to assess the probable effects of the 5 schedules on human cognitive performance effectiveness. This method was used previously to assess CF aircrew fatigue conducting Tactical Airlift Operations in support of our troops in Kabul (1). The simulation graphs are color-coded in the following manner. The top 10% of skilled performance is illustrated as a green band (from 100% to 90%) on the left ordinate on FAST models. The yellow zone (90% to 65% cognitive effectiveness) is equivalent to about 36 hrs of sleep deprivation. The pink zone (below 65%) is equivalent to 48 hrs of sleep deprivation. The left-hand ordinate quantifies cognitive performance effectiveness, scaled from 100% and down. The right-hand ordinate quantifies the acrophase (a measure of when best daily performance occurs) in hour of the day.

Given that we understand to some degree the context of using 24-h shifts in urban firefighting, the question is whether 24-h shift lengths for firefighters are truly acceptable in terms of the firefighting system. This is a system within which the firefighter is but one component, along with equipment, environment, fire type, etc. Is the firefighter on a 24-h shift safe and effective when fighting a fire? Or does he or she impair system performance due to cumulative fatigue acquired from a poor shiftwork schedule?

Methods & Results

The impact of each of the 5 schedules is modeled in 2 ways; 1) **with no fires/emergencies** to which the fire fighters must respond, and 2) **with fires/emergencies** to which the firefighters must respond. In all cases:

- Day shifts are simulated from 0800 h to 1800 h
- Night shifts are simulated 1800 h to 0800 h
- Rest during night shifts is simulated between 2300 h and 0630 h.

The simulations for each of the 5 schedules (when there NO alarms/fires to which the fire fighters must respond) are listed as Figures 1 through 5 in Appendix A.

Simulations with No Fires/Emergencies

Schedule 1. A 28-day cycle:

- Four (10 hr) day shifts
- Six days off
- Four (14 hr) night shifts
- Four days off
- Three (10 hr) day shifts
- Three (14hr) night shifts
- Four days off

This is a 4-crew, 2nW/2nF system with n = 7 and cycle length = 28d (W are work days, and F are free days on which no shift starts). The schedule uses nominal 12-h shifts with a shift-length differential where D = 10h and N = 14h; the *rota* is:

DDDDOOOOOONNNNOOOODDDNNNOOOO.

where D is a day shift, N is a night shift and O is a day off on which no shift starts.

Generally, this schedule sustains performance in the range of 100% to 90% except for very small, normal excursions down to about 88% just before bed-time at 2300 hrs during the night shifts (Figure 1). The acrophase is stable which illustrates that in the absence of night alarms, this schedule does not result in a circadian phase change.

Schedule 2. A 28-day cycle with a 24-hr Sunday:

- Four (10 hr) day shifts
- Six days off
- Three (14 hr) night shifts
- Five days off
- Two (10 hr) day shifts
- 14 hrs off
- One (24 hr) work period
- 10 hrs off

- Two (14 hr) night shifts
- Four days off

This is a 4-crew, 2nW/2nF system with n = 7 and cycle length = 28d. The schedule uses nominal 12-h shifts with a shift-length differential where D = 10h and N = 14h. Work compression is used by doubling shifts to build a 24-h work period (in parens in the *rota* below) and embedding the 24-h work period between two half-days off. The *rota* is:

DDDDOOOOOONNNOOOOODD½(DN)½NNOOOO

This schedule is similar to schedule 1 in that generally performance is in the range of 100% to 90% except for short, normal excursions which reach 85% cognitive effectiveness just before 2300 hrs bed-time on the third night shift and on the second of two night shifts at the end of the schedule (Figure 2). The acrophase is stable which illustrates that in the absence of night alarms, this schedule does not result in a circadian phase change.

Schedule 3. A 3-day/3-night schedule:
- Three (10 hr) day shifts
- Three (14 hr) night shifts
- Six days off.

This is a 4-crew, 2nW/2nF system with n = 3 and cycle length = 12d. The schedule uses nominal 12-h shifts with a shift-length differential where D = 10h and N = 14h. The *rota* is:

DDDNNNOOOOOO

This schedule is also similar to the previous two schedules in that just before the 2300 hr bed-time during the 3 night shifts cognitive effectiveness drops to 88, 86, and 84% for each of night shifts 1, 2, and 3 respectively (Figure 3). Other than these excursions, performance is in the 100% to 90% band. The acrophase is stable which illustrates that in the absence of night alarms, this schedule does not result in a circadian phase change.

Schedule 4. A 24-hr/72-hr proposed schedule:
- 24 hours on
- 72 hrs off

This is a 4-crew, 1nW/3nF system with n = 1 and cycle length = 4d. The schedule uses a 24-h shift length. The *rota* is:

WOOO

where W is one 24-hr work period.

Again, schedule 4 is similar to the previous schedules in that cognitive effectiveness is generally in the 100% to 90% band, but just before the 2300 hrs bed-time cognitive effectiveness drops to about 88% (Figure 4). The acrophase is stable which illustrates that in the absence of night alarms, this schedule does not result in a circadian phase change.

Schedule 5. A 24-hr proposed schedule:

- 24-hrs on
- 24-hrs off
- 24-hrs on
- 120-hrs off

This is a 4-crew, 1nW/3nF system with n = 2 and cycle length = 8d. The schedule uses a 24-h shift length. The *rota* is:

WOWOOOOO

Like all 4 previous schedules, cognitive performance is generally sustained in the 100% to 90% cognitive effectiveness band except just before the 2300 hrs bed-time at which point cognitive effectiveness is about 88% (Figure 5). The acrophase is stable which illustrates that in the absence of night alarms, this schedule does not result in a circadian phase change.

Simulations <u>with</u> Fires/Emergencies

The simulations for each of the 5 schedules (when there ARE alarms/fires to which the fire fighters must respond) are shown as Figures 6 through 10 in Appendix A. In all cases, there is a single alarm at 0200 hrs where the firefighters engage in responding to a fire and return to the fire station at 0500 hrs, at which time they return to bed until 0630 hrs. Otherwise, each schedule is exactly the same as described, above.

Schedule 1. Upon wakening at 0200 hrs when the alarm sounds in the first night shift, cognitive effectiveness is about 79%, and falls on each of the subsequent 3 nights to 72%, 67%, and 64% respectively (Figure 6). Upon return to the fire station at 0500 hrs cognitive effectiveness during on first to the fourth night shifts are 79%, 73%, 69%, and 67% respectively. Upon awakening at 0630 hrs to prepare for the day shift, cognitive effectiveness from the first to the fourth shifts respectively are 82%, 76%, 73%, and 72%. After the alarms on these 4 night shifts, cognitive effectiveness takes 2 days to recover with average day-time performance being 92% and 96% for day 1 and day 2 respectively. Also as a result of the alarms over the 4 nights, the acrophase (a measure of optimum daily performance) is delayed by almost an hour. This one hour circadian phase delay is directly attributable to the middle of the night work.

Schedule 2. Upon wakening at 0200 hrs when the alarm sounds in the first night shift cognitive effectiveness is about 78%, and falls on each of the subsequent 2 nights to 72%, and 65% respectively (Figure 7). Upon return to the fire station at 0500 hrs cognitive effectiveness during on first to the third night shifts are 79%, 73%, and 68% respectively. Upon awakening at 0630 hrs to prepare for the day shift, cognitive effectiveness from the first to the third shifts respectively are 82%, 75%, and 72%. After the alarms on these 3 night shifts, cognitive effectiveness takes 3 days to recover with average day-time performance being 78%, 92%, and 94% for day 1, day 2, and day 3 respectively. Also as a result of the alarms over the 3 nights, the acrophase (a measure of optimum daily performance) is delayed by almost an hour. Again, this one hour circadian phase delay is directly attributable to the middle of the night work.

Schedule 3. Upon wakening at 0200 hrs when the alarm sounds in the first night shift cognitive effectiveness is about 78%, and falls on each of the subsequent 2 nights to 71%, and 66% respectively (Figure 8). Upon return to the fire station at 0500 hrs cognitive effectiveness during the first to the third night shifts are 79%, 72%, and 68% respectively. Upon awakening at 0630 hrs to prepare for the day shift, cognitive effectiveness from the first to the third shifts respectively are 82%, 75%, and 72%. After the alarms on these 4 night shifts, cognitive effectiveness takes 3 days to recover with average day-time performance being 87%, 91%, and 94% for day 1, day 2, and day 3 respectively. Also as a result of the alarms over the 3 nights, the acrophase (a measure of optimum daily performance) is delayed by almost an hour. Again, this one hour circadian phase delay is directly attributable to the middle of the night work.

Schedule 4. Unlike the previous 3 schedules there is only one 24-hr shift. When the alarm sounds at 0200 hrs, cognitive effectiveness is 78% (Figure 9). When the fire fighters return to the station at 0500 hrs their cognitive effectiveness is 79%, and upon awakening at 0630 hrs, cognitive effectiveness is 82%. After the alarm on the single night shift, cognitive effectiveness takes 2 days to recover with average day-time performance being 92% and 94%, for day 1 and day 2 respectively. Also a result of the night alarm, the acrophase (a measure of optimum daily performance) is delayed by almost 30 minutes.

Schedule 5. When the alarm goes off at 0200 hrs in the first night shift, cognitive effectiveness is 78% (Figure 10). When the fire fighters return to the station at 0500 hrs, cognitive effectiveness is 79%, and upon awakening at 0630 hrs cognitive effectiveness is 82%. There is a partial recovery during the next 24-hr period when they are not on duty. Cognitive effectiveness at the commencement of the 2nd 24-hr shift was 94% rather than 98% at the commencement of the 1st 24-hr shift. The main consequence of commencing a shift when not fully recovered is that performance will fall faster than in someone who is completely rested before commencing the same shift. During the next night shift (24 hrs after the first shift), cognitive effectiveness is 74% when the alarm goes off at 0200 hrs, is 77% when the firefighters return to the fire station at 0500 hrs and is 79% upon awakening at 0630 hrs. After the night alarms during the 1st and 2nd shifts, even though the shifts are separated by 24 hours, cognitive effectiveness takes two days to recover with average day-time performance being 92% and 94% on day 1 and day 2 respectively. As a result of the night alarms, the acrophase (a measure of optimum daily performance) is delayed by almost an hour.

Discussion and Conclusions

All five schedules were predicted to sustain cognitive performance acceptably as long as there are no alarms during the night.

The "night run" manipulation produced about the same single-night result in all schedules, as one would expect since the sleep and night-run times were the same for all schedules. The first three schedules all involved either three or four nights of duty in a row and when alarms occurred during each of these nights, cognitive performance was impacted on the first night and got progressively worse over the next two nights.

Schedules 4 and 5 did not involve successive duty days. During the first duty night, an alarm on both schedules 4 and 5 resulted in similar impacts on cognitive effectiveness as the schedules 1 to 3. However, since there was no duty the subsequent day, cognitive performance recovered somewhat the next day. In the case of schedule 4, since the 24-hr shift was follow by 72 hours off, cognitive effectiveness was recovered fully before the next shift. In the case of schedule 5, because the 2^{nd} duty period occurred within 24 hrs of the 1^{st} duty period, recovery was not complete and cognitive effectiveness was somewhat lower in the 2^{nd} duty period

The deciding factor in these differences was the sequence of potential exposures of the firefighter to sleep deprivation due to nocturnal alarms. Days off between nocturnal alarms allowed a prediction of recovery between nights. Obviously, the sequence that produced cumulative fatigue was broken when the firefighter did not work on sequential night shifts and was not exposed to sequential nocturnal alarms.

There is a direct reciprocity between expansions and compression of work periods and time-off. The reciprocity is driven by the zero-sum nature of the clock and calendar. One must be compressed if the other expands. For example, there are 169 hours in a week and more hours spent on duty means fewer hours spent recovering on time off. To prevent the firefighter from being exposed to sequences of nocturnal alarms, one may use work compression. This is the primary difference between the set of Schedules 1, 2 and 3 and the set of Schedules 4 and 5. In the second set, work is compressed into a 24-h period. This allows an expansion of contiguous time off within the work week and work month. (We note that the 24-h work period in Schedules 4 and 5 may also be characterized as double shifts; that is a 10-h day shift followed immediately by a 14-h night shift.)

We suspect that the 24-h total work period length is acceptable, for two main reasons. First, there is a sleep-on-the-job mentality in the firefighter's job domain. This mentality should be encouraged in terms of "Any sleep is good." Second, the nocturnal component of the firefighter's work period exists only when there is an actual emergency and often follows a partial night of sleep. Thus, in many cases, there is a sleep-recency effect during nocturnal work. This gives the firefighter an advantage over other night workers who, because of job design, must work continually through the night and have no chance to sleep at night.

Finally, work compression does lead to longer contiguous periods of time off. Long contiguous periods of time off are probably a good idea for emergency workers who are under a relatively high threat of bodily injury or death on the job and who often undergo relatively high levels of physical and environmental stress (heavy fire protection gear, climbing, handling high pressure hoses, heat, etc.).

Given that 24 hours may be an acceptable work period length and that long contiguous time-off periods may be desirable, what might be an optimal schedule? With 4 crews, a given crew must work ¼ of the time. (This is a nominal value for calculation purposes; actually, they work slightly less than ¼-time when additional manning to cover vacation and sick time is considered.) Thus, the crew might work 1 day (24-h shift) on and have 3 days off (Schedule 4), or 2 days on and 6 days off (one version of this approach is used for Schedule 5). With 6 days off, many firefighters will become involved in second jobs and/or extra schooling. As long as these activities do not impair their "fitness for duty" (or "readiness to perform") upon return to work, they should not be of concern to management.

With 3 crews, a given crew and the individuals on that crew must work 1/3 of the time (same caveat concerning additional manning to cover vacation and sick time). Thus, the crew might work 1 day (24-h shift) on and have 2 days off, or 2 days on and 4 days off. In terms of a balance between tax-supported expenditures for emergency workers and the work demand on firefighters, the 3-crew, 2 on - 4 off schedule might be a good choice. However, the employer might see personnel attrition because of more attractive 4-crew operations with whom they must compete. Attrition may be affected by firefighters decisions to earn more money in a 3-crew, 56-h work week operation or to have more time off in a 4-crew, 42-h work week operation.

Recommendations

With respect to sustaining cognitive effectiveness in the face of nocturnal alarms, clearly schedule 4 is the best schedule and schedule 5 is the second best.

Management should note that even on the 2^{nd} day off schedule 4 or schedule 5, recovery is still incomplete.

We noted that only 7.5 h of sleep were scheduled in the schedules provided to us. Sleep scientists and sleep clinicians recommend 8 h sleep per 24 h. Eight hours of sleep should be scheduled for these firefighters.

This simulation software does not yet have the ability to accommodate physical work intensity (in this case, the high metabolic demands of fire fighting). Nevertheless, all 5 schedules were compared equally in this regard in that no accommodations were made for physical work effort on any of the 5 schedules. However, we are recommending to the developers of this simulation that input for physical work effort be accommodated in the future.

References

1. Paul MA, Miller JC. Fatigue assessment in Camp Mirage CC130 Aircrew: *Recommendations for pharmacologic intervention*. TR 2004-021. DRDC-Toronto.

2. Hursh SR, Redmond DP, Johnson ML, Thorne DR, Belenky G, Balkin TJ, Miller JC, Eddy DR, Storm WF (2003). The DOD Sleep, Activity, Fatigue and Task Effectiveness Model. *Proceedings of the 12th Conference on Behavior Representation in Modeling and Simulation (BRIMS 2003)*, 03-BRIMS-001, 14-15 May 2003, Mesa, Arizona.

Appendix A: *FAST*™ Simulations, no alarms

Figure 1. The 28-day cycle (Schedule 1) with no alarms.

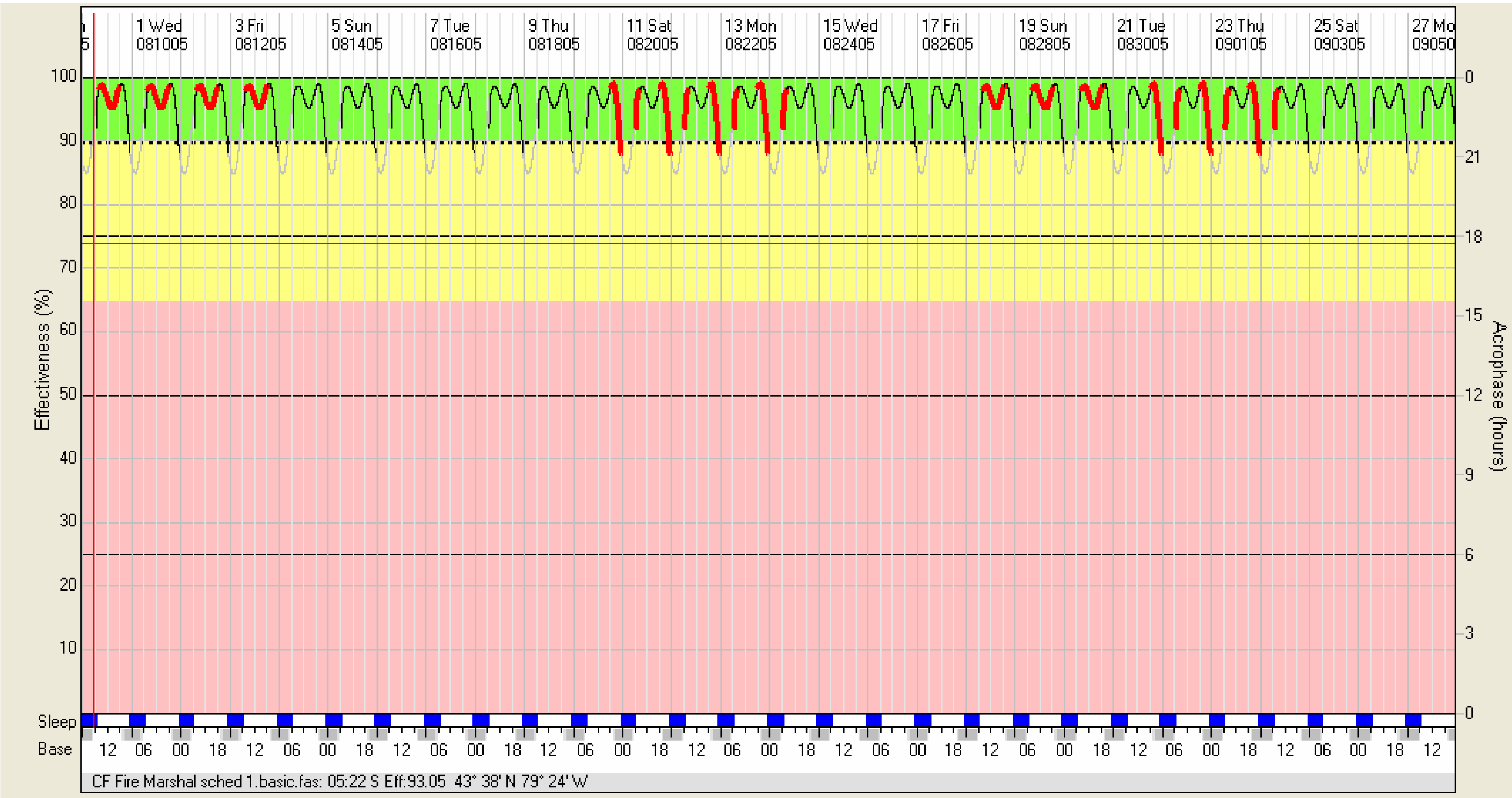


Figure 2. The 28-day cycle with a 24-hr Sunday (Schedule 2) with no alarms.

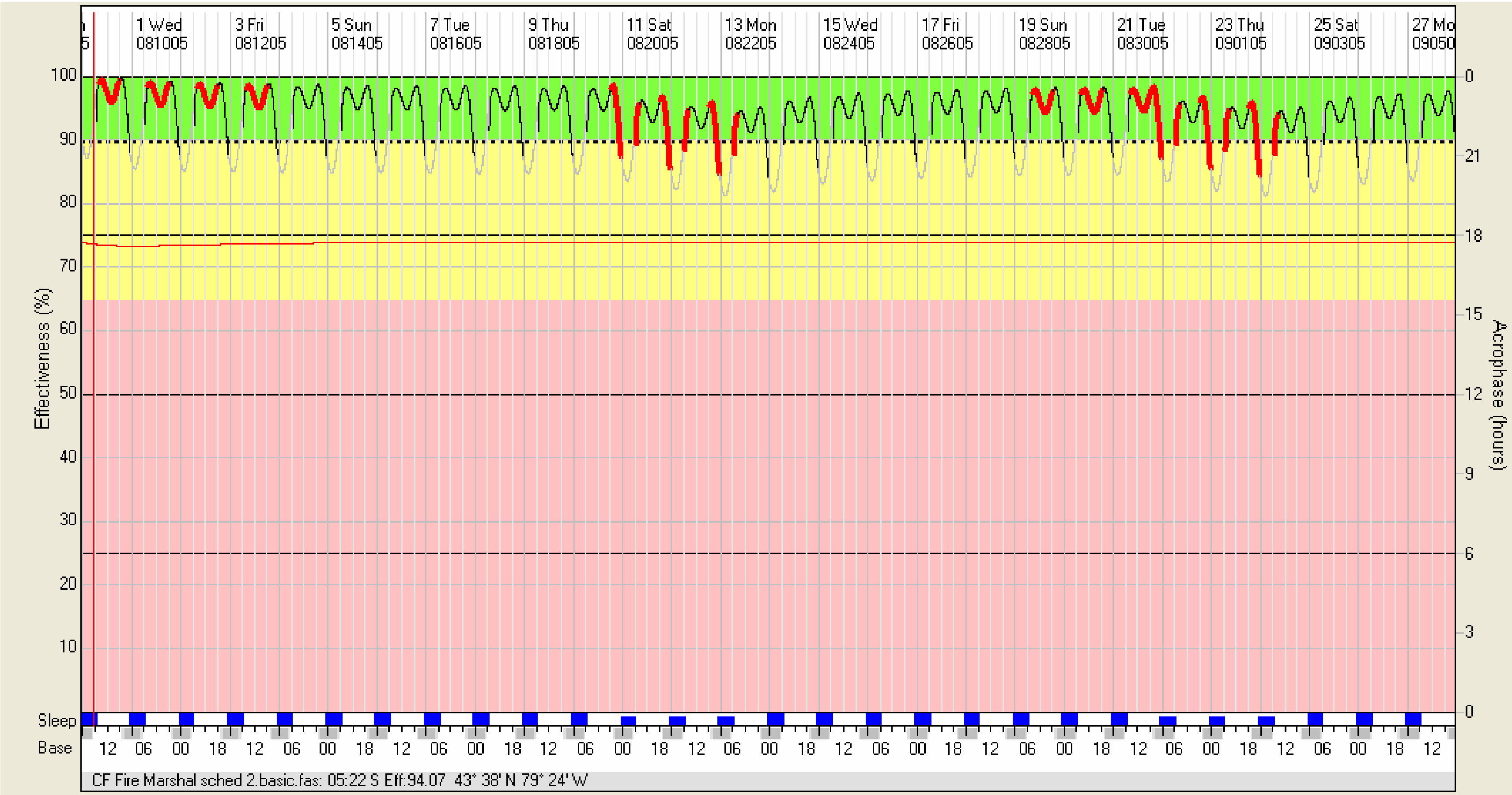


Figure 3. The 3-day/3-night shift (Schedule 3) with no alarms.

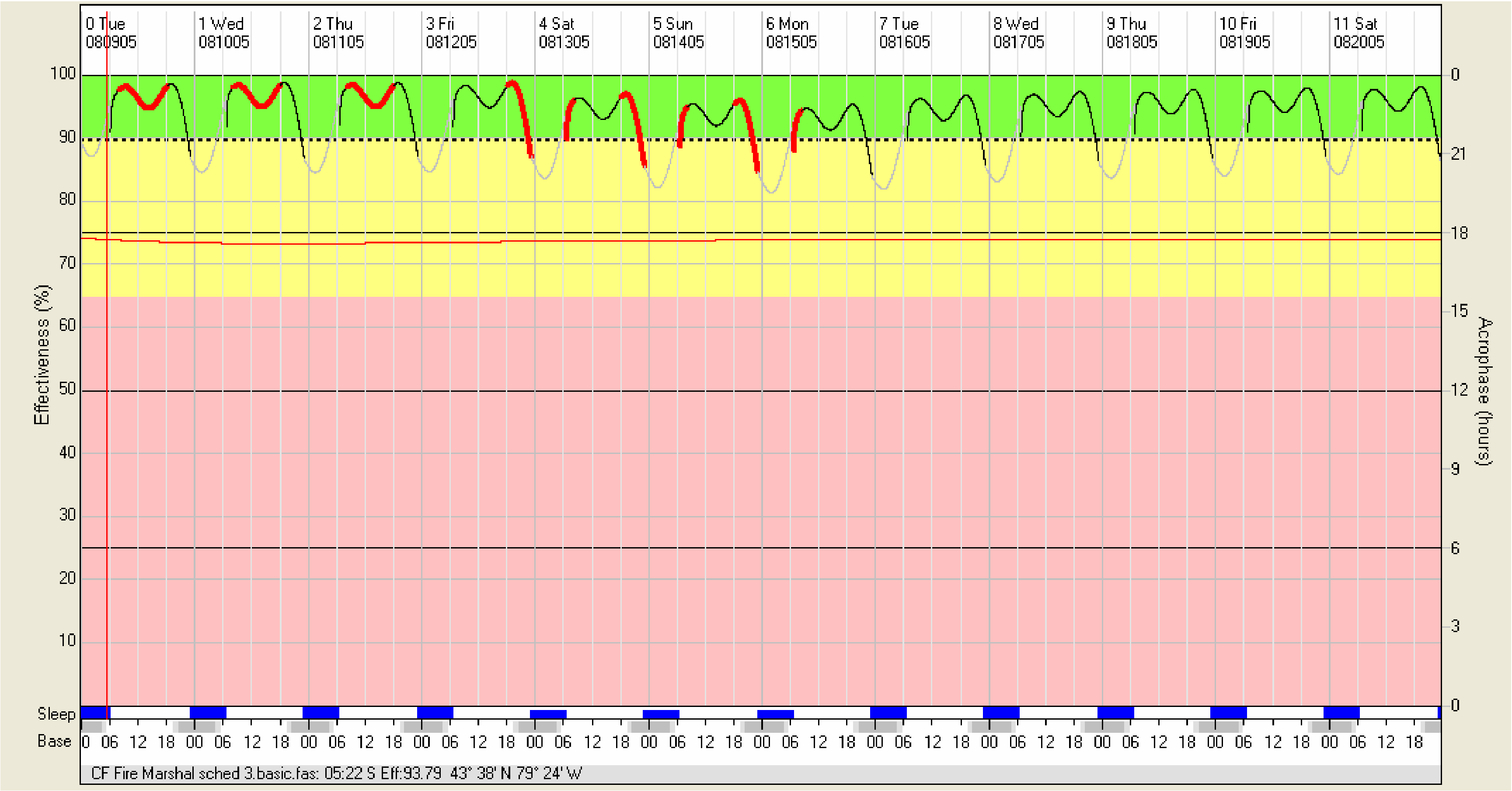


Figure 4. The 24-hr/72-hr proposed shift (Schedule 4) with no alarms.

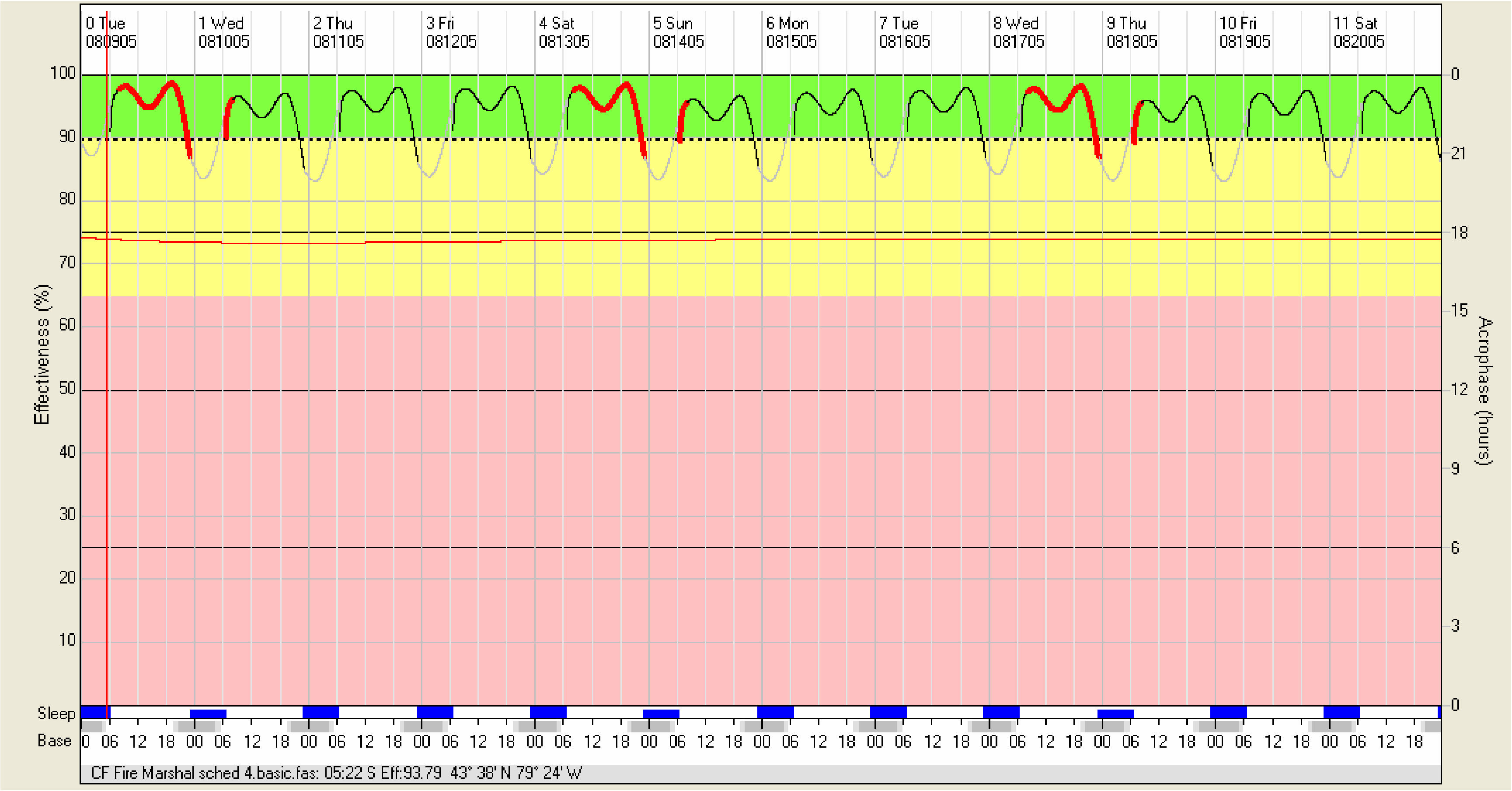
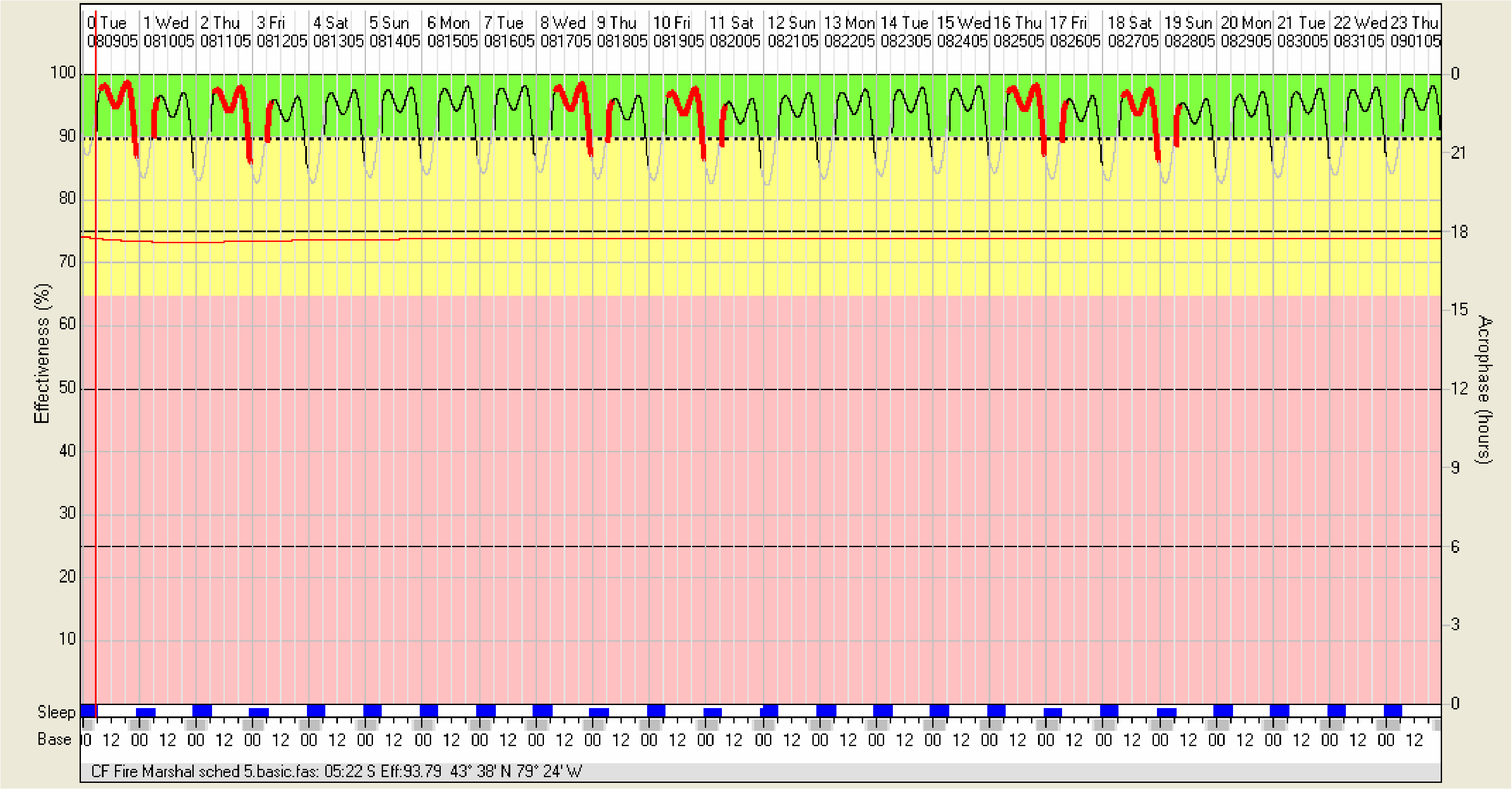


Figure 5. The 24-hr proposed shift (Schedule 5) with no alarms.



Appendix B: *FAST*^{TM} Simulations, with nocturnal alarms

Figure 6. Schedule 1 with 1 alarm per night for each of 4 nights in a row.

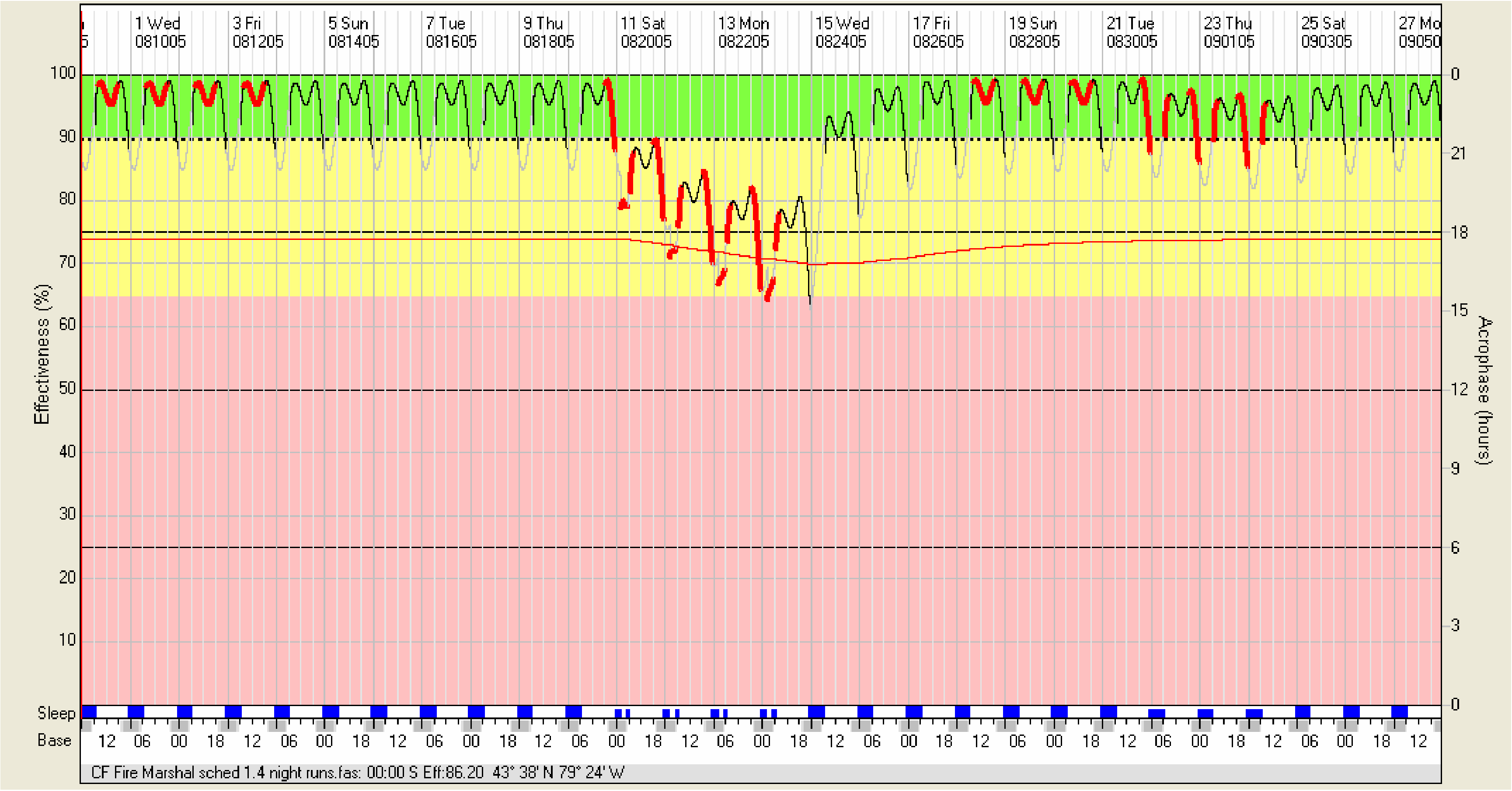


Figure 7. Schedule 2 with 1 alarm per night for each of 3 nights in a row.

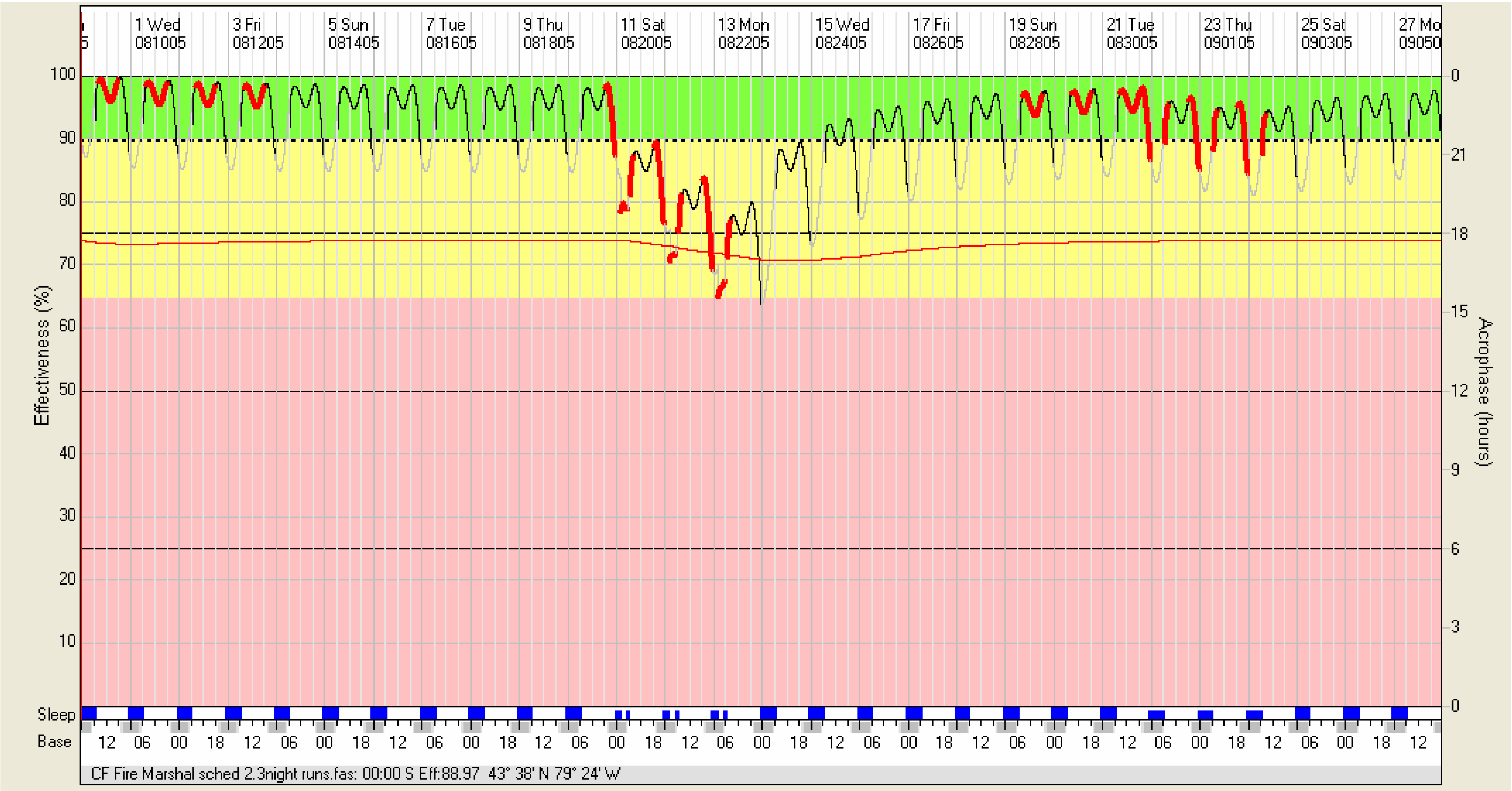


Figure 8. Schedule 3 with 1 night alarm per night for each of 3 nights in a row.

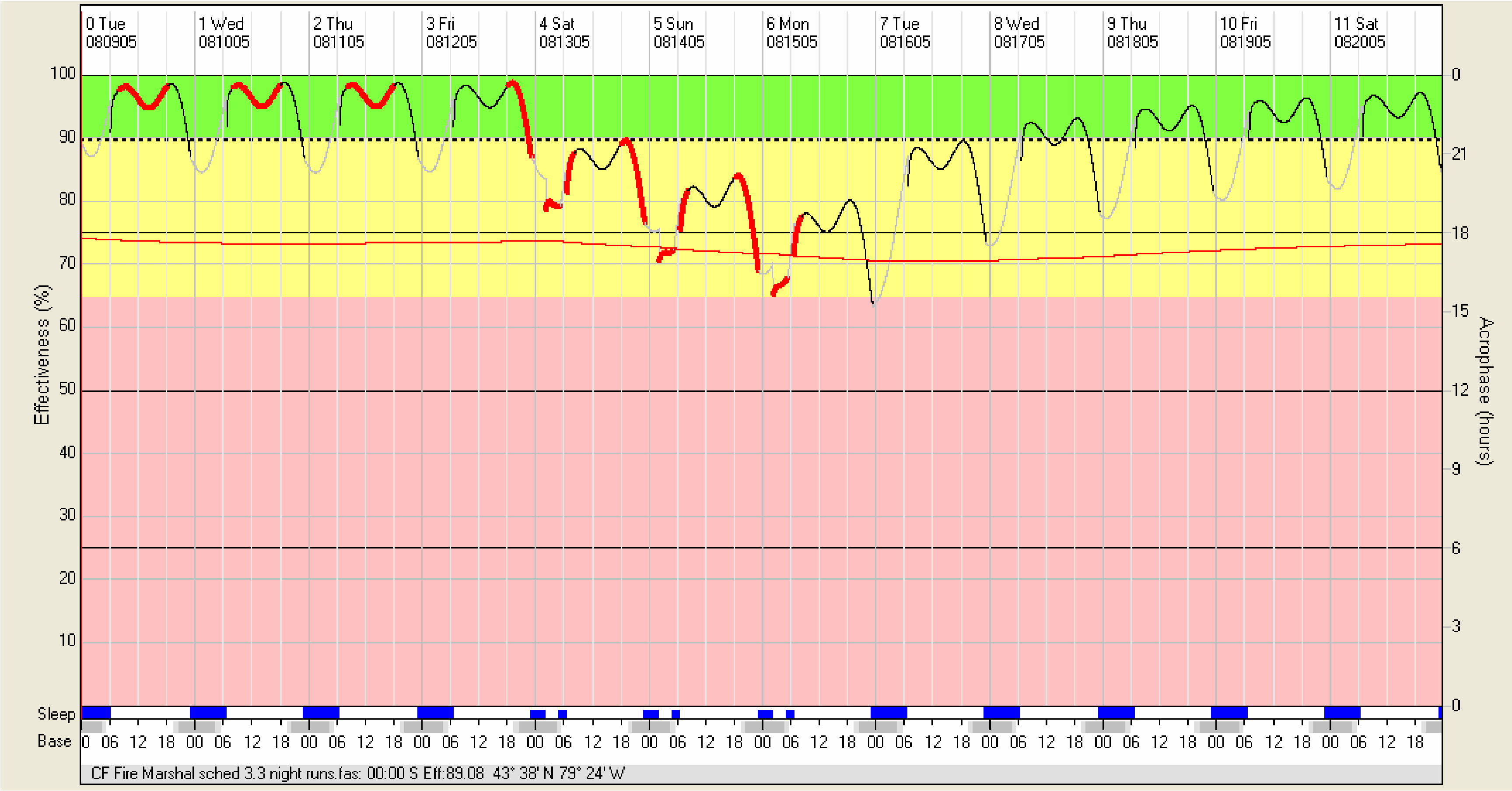


Figure 9. Schedule 4 with 1 night alarm on one shift.

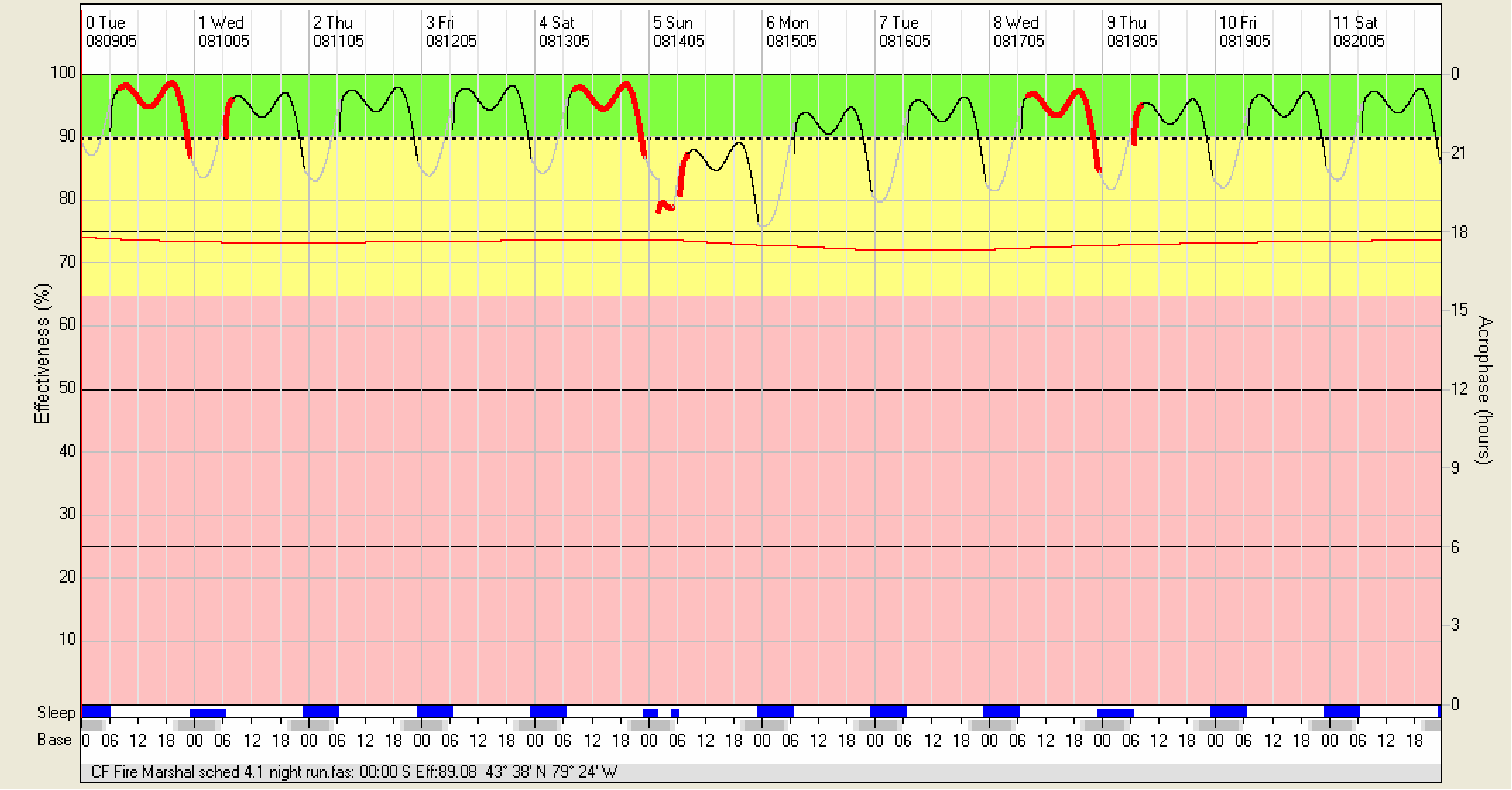
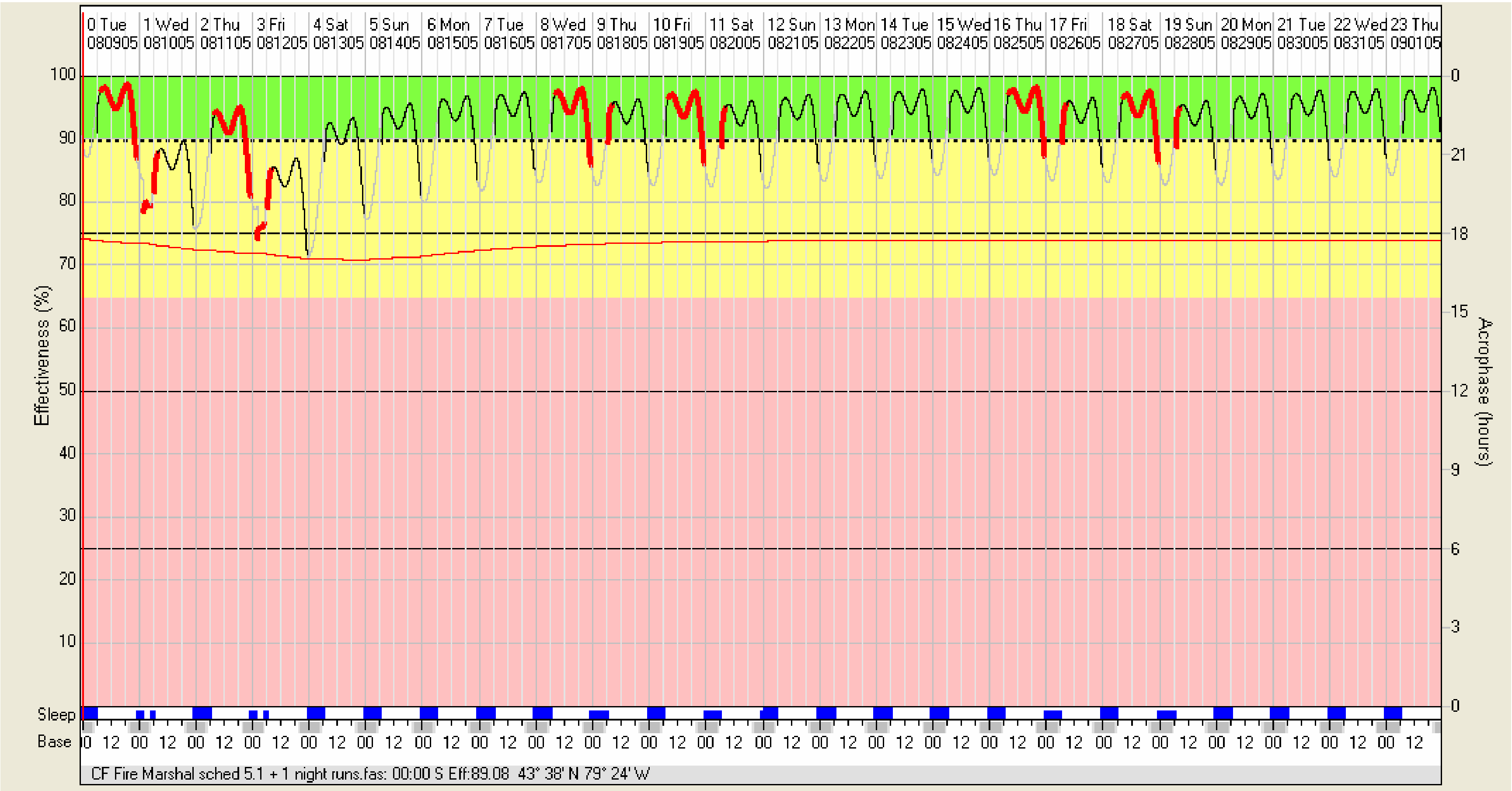


Figure 10. Schedule 5 with 1 night alarm followed by 24 hrs off, followed by 1 night alarm on next shift.



Appendix C: The Sleep, Activity, Fatigue and Task Effectiveness (SAFTE) Model and the Fatigue Avoidance Scheduling Tool (*FAST*™)

The Sleep, Activity, Fatigue and Task Effectiveness (SAFTE) model integrates quantitative information about (1) circadian rhythms in metabolic rate, (2) cognitive performance recovery rates associated with sleep, and cognitive performance decay rates associated with wakefulness, and (3) cognitive performance effects associated with sleep inertia to produce a 3-process model of human cognitive effectiveness.

- The SAFTE model has been under development by Dr. Steven Hursh for more than a decade. Dr. Hursh, formerly a research scientist with the Army, is employed by SAIC (Science Applications International Corporation) and Johns Hopkins University and is currently under contract to the WFC (Warfighter Fatigue Countermeasures) R&D Group and NTI, Inc. to modify and expand the model.

- The general architecture of the SAFTE model is shown in Figure 1. A circadian process influences both cognitive effectiveness and sleep regulation. Sleep regulation is dependent upon hours of sleep, hours of wakefulness, current sleep debt, the circadian process and sleep fragmentation (awakenings during a sleep period). Cognitive effectiveness is dependent upon the current balance of the sleep regulation process, the circadian process, and sleep inertia.

Schematic of SAFTE Model

Sleep, Activity, Fatigue and Task Effectiveness Model

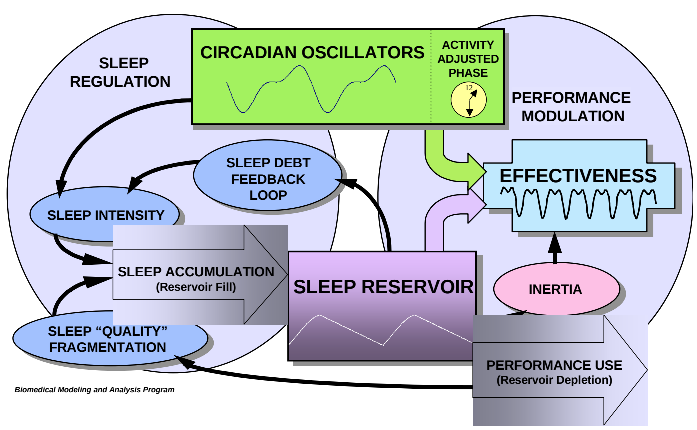


Figure 11. Schematic of SAFTE Model

- SAFTE has been validated against group mean data from a Canadian laboratory that were not used in the model's development (Hursh et al., in review). Additional laboratory and field validation studies are underway and the model has begun the USAF Verification, Validation and Accreditation (VV&A) process.

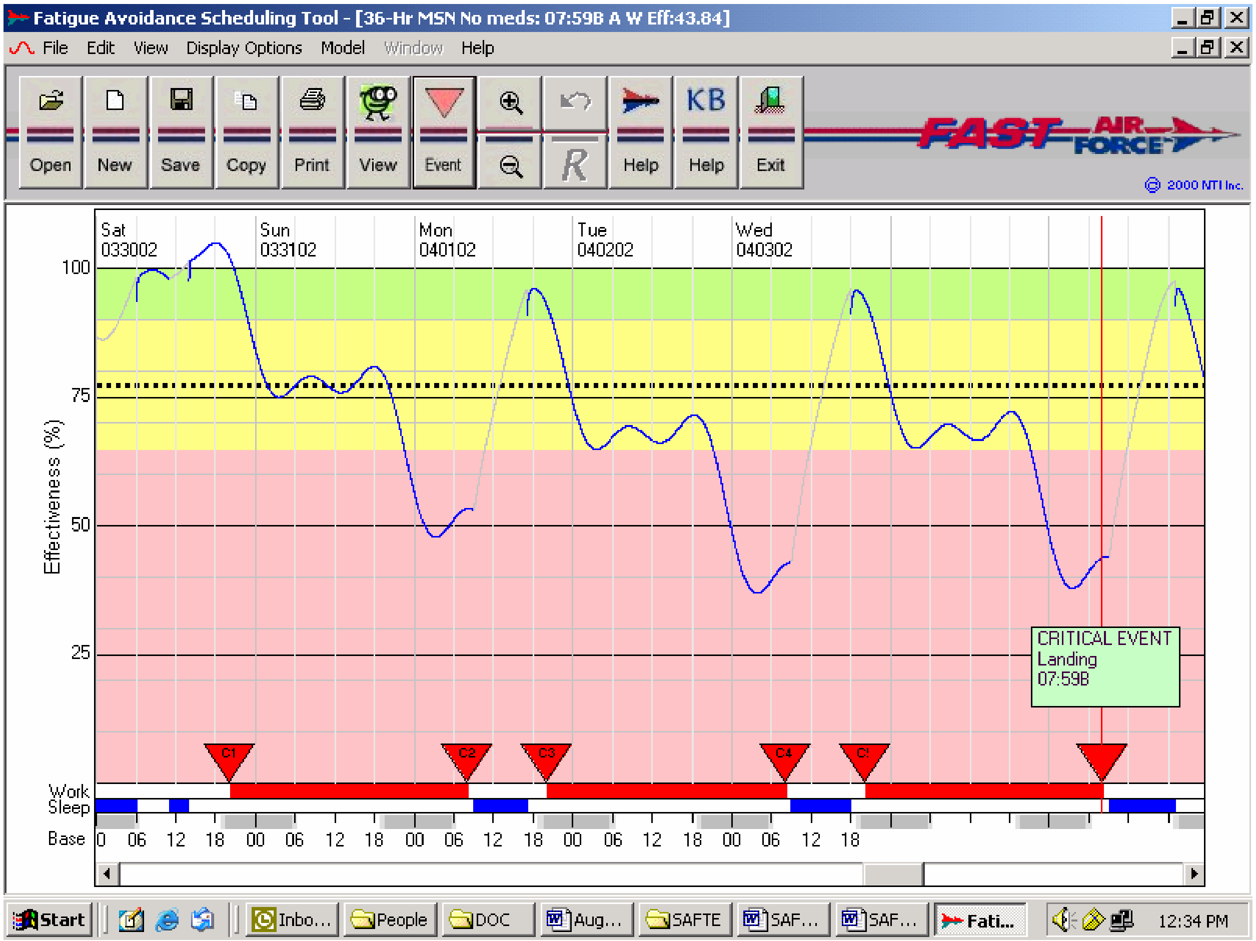
- The model does not incorporate the effects of pharmacological alertness aids; chronic fatigue (motivational exhaustion); chronic fatigue syndrome; fatiguing physiological factors such as exercise, hypoxia or acceleration; sleep disorders; or the fatiguing effects of infection.

The SAFTE Model has a number of essential features that distinguish it from other attempts to model sleep and fatigue (Table 1). Together, these features of the model allow it to make very accurate predictions of performance under a variety of work schedules and levels of sleep deprivation.

Table D-I. SAFTE model essential features.

KEY FEATURES	ADVANTAGES
Model is homeostatic. Gradual decreases in sleep debt decrease sleep intensity. Progressive increases in sleep debt produced by extended periods of less than optimal levels of sleep lead to increased sleep intensity.	Predicts the normal decline in sleep intensity during the sleep period. Predicts the normal equilibrium of performance under less than optimal schedules of sleep.
Model delays sleep accumulation at the start of each sleep period.	Predicts the detrimental effects of sleep fragmentation and multiple interruptions in sleep.
Model incorporates a multi-oscillator circadian process.	Predicts the asymmetrical cycle of performance around the clock.
Circadian process and Sleep-Wake Cycle are additive to predict variations in performance.	Predicts the mid-afternoon dip in performance, as well as the more predominant nadir in performance that occurs in the early morning.
Model modulates the intensity of sleep according to the time of day.	Predicts circadian variations in sleep quality. Predicts limits on performance under schedules that arrange daytime sleep.
Model includes a factor to account for the initial lag in performance upon awakening.	Predicts sleep inertia that is proportional to sleep debt.
Model incorporates adjustment to new time zones or shift schedules	Predicts temporary “jet-lag” effects and adjustment to shift work

The Fatigue Avoidance Scheduling Tool (*FAST*™) is based upon the SAFTE model. *FAST*™, developed by NTI, Inc. as an AF SBIR (Air Force, Small Business Innovative Research) product, is a Windows® program that allows planners and schedulers to estimate the average effects of various schedules on human performance. It allows work and sleep data entry in graphic and text formats. A work schedule comprised of three 36-hr missions each separated by 12 hours is shown as red bands on the time line across the bottom of the graphic presentation format in Figure 2. Average performance effectiveness for work periods may be extracted and printed as shown in the table below the figure.



AWAKE			WORK		
Start Day - Hr	Duration (Minutes)	Mean Effectiveness	Start Day - Hr	Duration (Minutes)	Mean Effectiveness
0 - 06:00	300	98.97	0 - 20:00	1079	81.14
0 - 14:00	2580	76.42	1 - 14:00	1080	63.97
2 - 17:00	2400	64.78	2 - 20:00	1079	71.23
4 - 18:00	2340	64.58	3 - 14:00	1080	54.51
6 - 19:00	1741	72.23	4 - 20:00	1079	72.00
			5 - 14:00	1080	54.92

Figure 12: Sample FAST^{tm} display. The triangles represent waypoint changes that control the amount of light available at awakening and during various phases of the

circadian rhythm. The table shows the mission split into two work intervals, first half and second half.

- Sleep periods are shown as blue bands across the time line, below the red bands.
- The vertical axis of the diagram represents composite human performance on a number of associated cognitive tasks. The axis is scaled from zero to 100%. The oscillating line in the diagram represents expected group average performance on these tasks as determined by time of day, biological rhythms, time spent awake, and amount of sleep. We would expect the predicted performance of half of the people in a group to fall below this line.
- The green area on the chart ends at the time for normal sleep, ~90% effectiveness.
- The yellow indicates caution.
- The area from the dotted line to the red area represents performance level during the nadir and during a 2nd day without sleep.
- The red area represents performance effectiveness after 2 days and a night of sleep deprivation.

The expected level of performance effectiveness is based upon the detailed analysis of data from participants engaged in the performance of cognitive tasks during several sleep deprivation studies conducted by the Army, Air Force and Canadian researchers. The algorithm that creates the predictions has been under development for two decades and represents the most advanced information available at this time.

3. Hursh SR, Redmond DP, Johnson ML, Thorne DR, Belenky G, Balkin TJ, Miller JC, Eddy DR, Storm WF (2003). The DOD Sleep, Activity, Fatigue and Task Effectiveness Model. *Proceedings of the 12th Conference on Behavior Representation in Modeling and Simulation (BRIMS 2003)*, 03-BRIMS-001, 14-15 May 2003, Mesa, Arizona.

Glossary

Technical term	Explanation of term
acrophase	The timing of the circadian peak relative to midnight.
acrophase time	The time of night or day at which the circadian peak occurs.
circadian	From the latin *circa* (about) and *dia* (day): a cycle length of about one day. That is, one high point (peak) and one low point (rough, or nadir) per 24 hours.
rota	A shift plan.

UNCLASSIFIED

DOCUMENT CONTROL DATA (Security classification of the title, body of abstract and indexing annotation must be entered when the overall document is classified)	
1. ORIGINATOR (The name and address of the organization preparing the document, Organizations for whom the document was prepared, e.g. Centre sponsoring a contractor's report, or tasking agency, are entered in section 8.) Publishing: DRDC Toronto Performing: DRDC Toronto Monitoring: Contracting: DRDC Toronto	2. SECURITY CLASSIFICATION (Overall security classification of the document including special warning terms if applicable.) UNCLASSIFIED
3. TITLE (The complete document title as indicated on the title page. Its classification is indicated by the appropriate abbreviation (S, C, R, or U) in parenthesis at the end of the title) Consideration of 5 Canadian Forces Fire Fighter Shift Schedules (U)	
4. AUTHORS (First name, middle initial and last name. If military, show rank, e.g. Maj. John E. Doe.) Michel A. Paul; James C. Miller	

5. DATE OF PUBLICATION (Month and year of publication of document.)	6a NO. OF PAGES (Total containing information, including Annexes, Appendices, etc.)	6b. NO. OF REFS (Total cited in document.)
October 2005	35	2

7. DESCRIPTIVE NOTES (The category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.) Technical Report Consideration of 5 Fire Fighter Shift Schedules and recommendations for which of these is the optimum schedule	
8. SPONSORING ACTIVITY (The names of the department project office or laboratory sponsoring the research and development − include address.) Sponsoring: Tasking:	
9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant under which the document was written. Please specify whether project or grant.)	9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.)
10a. ORIGINATOR'S DOCUMENT NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document) DRDC Toronto TR 2005−227	10b. OTHER DOCUMENT NO(s). (Any other numbers under which may be assigned this document either by the originator or by the sponsor.)
11. DOCUMENT AVAILABILIY (Any limitations on the dissemination of the document, other than those imposed by security classification.) Unlimited distribution	
12. DOCUMENT ANNOUNCEMENT (Any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11), However, when further distribution (beyond the audience specified in (11) is possible, a wider announcement audience may be selected.)) Unlimited announcement	

UNCLASSIFIED

DOCUMENT CONTROL DATA

(Security classification of the title, body of abstract and indexing annotation must be entered when the overall document is classified)

13. ABSTRACT (A brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual.)

(U) INTRODUCTION. DRDC Toronto received a BL−2 tasking from the CF Fire Marshall to assess 5 different fire fighter schedules, along with a request for DRDC Toronto to recommend which of the 5 schedules is “optimum”. Any skilled performance or safety critical performance should occur when personnel are operating at their best. Best performance is normally considered to mean between 100% and 90% cognitive effectiveness. When performance declines to 90%, it is time to cease skilled operations and get some rest. METHODS. The duty times, and the sleep times for each of the 5 shift schedules were used as inputs to the FAST (Fatigue Avoidance Scheduling Tool) Program (a modelling program which calculates cognitive effectiveness as a function of duty and rest cycles). Each of the 5 shift schedules was modelled in 2 ways; 1) first with no fires/emergencies, and 2) subsequently with nocturnal alarms occurring at 0200 hrs and the fire fighters returning to the fire hall at 0500 hrs. RESULTS. With no fires/emergencies all 5 schedules resulted in similar small impacts on cognitive effectiveness (from 84% to 88%) just before retiring for bed around 2300 hrs. The nocturnal alarms caused some attrition of cognitive effectiveness on the subsequent day which ranged from 82% to 79%, and after several days (for schedules 1, 2, and 3) cognitive effectiveness declined further to the 72% to 68% range. Schedules 4 and 5 did not involve successive duty days. During the first duty night, an alarm on either schedule 4 or schedule 5 resulted in similar impacts on cognitive effectiveness as schedules 1 to 3. However, since there was no duty the subsequent day, cognitive effectiveness recovered somewhat the next day. In the case of schedule 5, since the 24−hr shift was followed by 72 hours off, cognitive effectiveness was fully recovered before the next shift. In the case of schedule 5, because the 2nd duty period occurred within 24 hrs of the 1st duty period, recovery was not complete and cognitive effectiveness was somewhat lower in the 2nd duty period. CONCLUSIONS. All five schedules were predicted to sustain cognitive performance as long as there are no alarms during the night. If night−time alarms occur, impact on cognitive effectiveness occurs similarly across all schedules with recovery of cognitive effectiveness taking up to 48 hrs. However, since schedule 4 provides for 3 days of rest after each 24−hr work period, cognitive performance is fully restored before the next duty period. RECOMMENDATIONS. With respect to sustaining cognitive performance in the face of nocturnal alarms, clearly schedule 4 is the best schedule and schedule 5 is the second best.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

(U) CF Fire Figher Shift Schedules
Sustainment of Cognitive Effectiveness

Defence R&D Canada

Canada's Leader in Defence
and National Security
Science and Technology

R & D pour la défense Canada

Chef de file au Canada en matière
de science et de technologie pour
la défense et la sécurité nationale

DEFENCE R&D DÉFENSE

www.drdc-rddc.gc.ca