

**A work-related fatigue model known
as Fatigue Audit InterDyne [FAID],
which uses hours-of-work as its
input: Background, validations,
interpretation of results, assumptions
and future work.**

Prepared by: Dr Adam Fletcher

May 2003 (first revision August 2004; this revision March 2005)

Section 1: Background and validation work

Our world is rapidly becoming a single, global 24-hour society. This society is driven by customer demands, community expectations and global competition and delivers unquestionable benefits. However, these benefits come with a range of costs. One of these costs is the increased prevalence of shiftwork and its associated fatigue. The most common problems reported by shiftworkers are disturbed sleep and sleepiness.

From a biological perspective this is not surprising because shiftworkers are often required to work at times when their mind and body are driven toward sleep. Shiftworkers may therefore be required to attempt sleep during the day; a time at which their mind and body are programmed to be awake and active. When sufficient recovery doesn't occur on a daily basis, sleepiness and fatigue can accumulate. Increased levels of sleepiness and fatigue generally manifest as poorer alertness, communication and performance as well as greater risk of injury and accidents.

Traditionally, shiftwork and the work-related fatigue that it can create have been 'managed' by limiting the length of shifts and total number of hours worked per week, month or year. This has been supported by employee awards and more recently by industrial documents such as enterprise bargaining agreements. However, this approach fails to acknowledge key factors such as the time-of-day of work.

Thus, considerable effort has gone into developing and validating tools that account for work-related fatigue in a more scientific and objective manner. Our group, the Centre for Sleep Research [CFSR] at the University of South Australia [UniSA], have been engaged in the development and validation of a tool known as Fatigue Audit InterDyne [FAID].

A large proportion of this work was reported in a Ph.D. awarded by UniSA (Fletcher, 1999). Subsequently, chapters of the thesis have been published in peer-reviewed scientific journals and books. In addition, validation studies have been carried out since the Ph.D. was completed and others are currently underway. More details about the thesis chapters are presented below and descriptions of completed and scheduled studies are provided in section four.

Chapter one of the thesis provided the relevant background and literature for work-related fatigue assessment. Areas covered include definitions of shiftwork and fatigue as well as the relationship between sleep deprivation, fatigue and accident risk. Chapter one also discussed the theoretical components that are required to quantify work-related fatigue. These components are time-of-day and length of shifts and breaks, prior work history and human limitations on recovery at different times of the day. The published versions of this work appeared in the journals

Occupational Health and Safety and Ergonomics as well as a book (Fletcher & Dawson, 1997; Fletcher & Dawson, 1998; Dawson & Fletcher, 2001).

Chapter two of the thesis provided the developmental framework for the work-related fatigue model. This model uses only shift start and finish times as inputs. Scores are produced for each hour of work that is entered into the model. The model allows comparisons to be made between rosters independent of the number of hours worked, the length of shifts worked or the timing of work and non-work periods. The mathematical structure of the model was also provided. The published version of this work appeared in the journal *Ergonomics* (Fletcher & Dawson, 2001a).

Chapter three of the thesis aimed to validate the model against a range of sleep deprivation experiments. A number of previously published studies had assessed cumulative effects of restricting night sleep to between four and five hours. The measures that were used for correlations between model predictions and published results include psychomotor vigilance task lapses, the slowest 10% of reaction time responses from a psychomotor vigilance task and multiple sleep latency tests. Further correlations were performed on measures from a continuous sleep deprivation data such as objective vigilance, subjective performance, sleepiness and tiredness. The 'goodness of fit' between fatigue scores and measured data were very strong and ranged from 56% [for objective vigilance and subjective performance] to 94% [for multiple sleep latency test scores]. Chapter three also outlined a range of theoretical validations against ergonomic recommendations of shift scheduling. A published version of this work has been submitted for publication to the *Journal for Sleep Research*.

Chapter four of the thesis aimed to further validate the work-related fatigue model by comparing model predictions to performance impairment measured under laboratory conditions. This chapter presented a study that equated performance impairment due to sleep deprivation, alcohol intoxication and work-related fatigue on a range of measures including grammatical reasoning, unpredictable tracking and vigilance. The relationships between fatigue scores and neurobehavioural performance was strong to very strong; the goodness of fit ranged from 40% to 71%. The results presented in chapter four include fatigue and blood alcohol concentration equivalents for these performance measures. The published version of this work appeared in the journal *Sleep Research Online* and a book (Fletcher, Lamond, van den Heuvel & Dawson, 2003; Fletcher, Roach, Lamond & Dawson, 2000).

The validations presented in chapter five of the thesis investigated the ability of the model to predict changes in work-related fatigue due to napping. Somewhat intuitively, the longer the sleep deprivation prior to a nap, the smaller the relative effect of the nap compared to overall

fatigue. Also, the longer the time period since the termination of a nap, the less relative effect the nap has on performance measures. With respect to time-of-day and nap effects on performance, there is little difference across daytime hours. However, naps taken at or near the circadian nadir in body temperature, and to a lesser extent, naps taken a number of hours either side of the nadir, produce larger positive effects on performance. Chapter five also showed comparisons of model predictions with data collected in laboratory studies that have used naps of two, four and eight hours duration. These naps had been scheduled before and after varying periods of wakefulness in a range of configurations. The results of these analyses confirmed that the model could predict changes in a range of measures.

Chapter six of the thesis reports on a field-based validation of the work-related fatigue model using 193 shiftworkers. These drivers had data collected from them during two weeks of their normal roster. The purpose of this study was to examine whether field-based validations of the work-related fatigue model produce correlations similar to those from theoretical and laboratory-based validations. The study used work-related scores based on actual hours of work, visual analogue scales [VASs] and scores from a neurobehavioural performance task.

The results of the study indicate that work-related fatigue scores and self-rated alertness at the beginning and end of shifts correlated significantly. The results also indicate that work-related fatigue scores and scores from the specific performance test used were not significantly related. The correlations in this validation confirm that relationships measured in the laboratory break down somewhat in operational environments. However, the strength of the relationships observed were consistent with the conclusions of other field-based studies. The published version of this work appeared in the journal *Transportation Research* (Fletcher & Dawson, 2001b).

Taken together, the results of the validations outlined above suggest that the FAID model is able to predict outcomes from a range of experimental studies. Specifically, the model predictions have accurately reflected both objective and subjective measures collected under conditions of normal sleep, sleep deprivation, napping and shiftwork. This suggests that predictions from the FAID model would accurately indicate the effects of specific hours-of-work schedules on measures such as self-rated sleepiness, vigilance, performance and sleep latency.

Section 2: Interpretation of FAID scores

By analysing a planned or actual set of work hours using FAID, a score is produced. This score is not a percentage but a number and can range from zero up to more than 140. From the results of the validation studies discussed in section 1, it can be generally stated that a FAID score of less

than 80 points is consistent with a safe system of work. Similarly, it can be generally stated that scores above 100 are consistent with an unsafe system of work. Scores between 80 and 100 cannot be broadly considered safe or unsafe unless the context of the work is known.

These general conclusions do not, however, negate the need for organisations using FAID to engage in risk assessments of specific works task and conditions. This section provides a summary of the experimental evidence from the fatigue model validations that lead to the general statements above. In addition, specific ranges of scores have been equated to blood alcohol concentration equivalents.

The initial set of data that was used to equate impairment due to fatigue with impairment due to alcohol intoxication was Dawson and Reid (1997). The results from FAID modelling of the sleep deprivation condition of this study indicated that a score of 80 is produced after 21-22 hours of continuous sleep deprivation; when the sleep deprivation begins at 0800h. As a relative reference, a score of 80 reflects approximately 200% of the maximum fatigue score obtained for a 0900 to 1700h, Monday to Friday workweek. In this analysis, the performance impairment at approximately 80 points equated to an equivalent performance impairment as observed in a subject with a blood alcohol concentration [BAC] of 0.05% or greater.

This reassessment of the Dawson and Reid study indicated that performance impairment at a FAID score of 80 points was comparable to the performance impairment of a BAC of 0.05% or greater. However, this initial study had only used one performance test to determine this level of equivalence. In order to obtain a more widely tested conclusion, it was decided that a similar study be run using a range of performance tests and not just one. Therefore, the identical protocol was run again using a range of performance measures (Fletcher, Lamond, van den Heuvel & Dawson, 2003). The performance tests were;

- A grammatical reasoning task [GRT],
- An unpredictable tracking task [TRK],
- A vigilance task [VIG], and
- A simple sensory comparison task [SSC].

The performance impairment observed at a particular fatigue score differs with each of these tests. This reflects the fact that different tests are more or less sensitive to fatigue. It is because of this range of sensitivities that we can better understand the impairment associated with a particular fatigue score. This is because, with a range of tests, we can observe the range of effects on different types of performance.

Of all of the tests used, the vigilance score was the measure that was most highly correlated with fatigue predictions. In fact, the fatigue predictions have a goodness of fit of 70% with the vigilance score data; in statistical terms this is considered to be a very strong relationship. Thus, the vigilance score results provide us with the best example to illustrate the relationship between impairment due to fatigue and impairment due to alcohol intoxication.

For vigilance score, performance decrements observed at a fatigue level of approximately 80 are associated with decrements equivalent to those seen at a blood alcohol concentration of 0.05% or greater. This finding supports the original observations made from the Dawson and Reid (1997) study. Furthermore, this conclusion is supported by the other measures that did not have as strong a relationship with fatigue predictions.

It is important to note that the FAID model does not account for individual differences. In addition, it is unlikely that any model could unless much more individual performance and/or sleep data was used. This lack of accounting for individual differences is similar to the law relating to the 0.05% BAC alcohol limit on the roads. This law does not account for individual differences in tolerance to alcohol.

Furthermore, the FAID model does not account for differences in specific tasks, environments or work pressures associated with the job that someone is doing. However, it is possible that factors such as individual differences and tasks will be able to be accounted for in future versions of the model. These areas of current and future work, as well as others, are outlined in section 4.

Until a model to account for such factors can be developed and assessed, a practical method for accounting for factors not accounted for by FAID is by using a risk management approach such as such as the Australian Standard for Risk Management [AS4360].

Relevant factors can be taken into consideration by determining their relative importance using a step-by-step procedure. In very simplified terms, a part of this procedure involves a group of employees assigning one of five pre-determined definitions to: 1) the likelihood, and 2) the consequence of all possible incidents and accidents. The one-to-five scale uses specific definitions of likelihood and consequence that are provided within AS4360.

Once likelihood and consequence scores have been assigned then a risk group is assigned according to a table in AS4360. The risk groups are 'low', 'moderate', 'high' and 'extreme'. Therefore, at the end of the risk management assessment each task or job that an employee may be required to do can have been assigned as being either 'low', 'moderate', 'high' and 'extreme'.

The definition of a job or task does not effect the accumulation of fatigue points within FAID. However, it is likely that the maximum level of fatigue that you would accept for a task assigned as 'high' risk would be lower than for a task assigned as a 'low' risk. For example, if someone were required to be photocopying training manuals, a 'low' risk task, then a maximum fatigue score of 80 should be acceptable. However, if a person were required to be flying a surveillance aircraft at low altitude then a lower maximum threshold of fatigue such as 65 may apply.

In summary, the most appropriate interpretation of FAID scores occurs by using a risk management process with regards to fatigue management. That is, to determine acceptable thresholds of maximum fatigue for different work tasks and conditions by taking into account all of the factors that might impact on a person's capacity to do a job safely.

Section 3: Assumptions

Although the FAID model has been shown to have high predictive power in theoretical and experimental studies, its applicability may be currently limited relative to its potential. Like any mathematical model, FAID incorporates assumptions into its workings. From a scientific perspective, there are a number of these assumptions that appear to be most likely to be currently limiting FAID from proving even more accurate in its predictions. This section outlines these limitations, which are currently being investigated and are further discussed in section 4.

The first assumption is that there is a fixed-phase relationship between circadian time and clock time. That is, it is currently assumed that the endogenous [internal] biological time does not adjust to abnormal sleep/wake cycles as imposed by irregular work patterns. However, this may not be the case in all circumstances. It is possible that even work schedules not involving time zone changes could create phase shifts of the endogenous biological time.

The second assumption is that neurobehavioural performance reaches a trough between 0400 and 0600h. This assumption is based on accepted data, however it would not be surprising if certain populations did not fit this assumption. For example, research has shown that older adults tend to go to bed and get up earlier and also shown an earlier trough. Alternatively, many young adults habitually go to bed and get up later and can show a delayed trough. Taken together, this suggests that it is possible that certain individuals or groups may not have their performance trough at 0400 to 0600h.

The third assumption is that the recuperative value of short sleeps [that is, naps] and normal sleeps are equivalent per unit time. However, naps may actually deliver a higher recovery value per unit time compared to other sleeps. Similarly, such a recovery profile might also be seen in

individuals sleeping after sleep deprivation. These observations suggest that increasing the value of recovery sleep obtained toward the earlier part of a sleep period could improve the predictive value of the model.

The fourth assumption is that a certain amount of sleep will be obtained in a given recovery period based on a statistical distribution of sleep across the 24-hour period. Recently acquired data from our group however, suggests that the pattern of sleep an individual will obtain, given a certain work and break pattern, can now be predicted with greater accuracy than when the model was first developed.

It is also possible that there are other assumptions of the model that are not listed here. Further assumptions will be investigated as they are identified. In the interim however, it is our group's intention to investigate each of these assumptions as well as other possible avenues for improving the FAID model's predictive power. These investigations and other completed and future work are discussed below in section 4.

Section 4: Current and future development and validation

In addition to the validations and studies outlined in the above sections, there have been other validation studies completed. Furthermore, numerous studies are also scheduled to begin during 2003 and 2004. This section outlines these completed and scheduled studies as well as potential model modifications that are being investigated.

Completed rail simulator validations

Since 1995, the CFSR has been undertaking research into shiftwork, workload and fatigue issues for a consortium of Australian railway operators. This relationship is into its third three-year phase, known as Phase III. In Phase II, which ran from 1999 to 2001, two rail simulator studies were undertaken that allowed for further validation of FAID.

Since FAID gives us quantitative measures of work-related fatigue it was possible to correlate these against actual driver performance in the simulator. The investigations in Phase II allowed for a simulator study in a heavy haul environment and another in an urban environment. There were differences identified across low, moderate and high fatigue states, as defined by FAID.

Distinct differences were also observed between heavy haul and urban environments. Most specifically, the heavy haul environment showed to be more sensitive to fatigue as defined by FAID. Significant increases in dangerous behaviours such as speeding violations over 25km/h above the speed limit were observed in the heavy haul environment. In the urban system, the effects are more subtle and would require additional study to make definitive conclusions.

Aviation validation in progress

As part of a large project currently underway between Qantas, the Civil Aviation Safety Authority, the Australian International Pilot's Association and the CFSR, a study is being undertaken to investigate fatigue in Boeing 747 simulators. In addition to the simulator performance measures, the Psychomotor Vigilance Task [PVT] will be used to assess reaction time, and Visual Analogue Scales [VASs] will be used to make self-ratings of alertness, fatigue, and performance. These objective and subjective measures can be used to further validate FAID.

Nearly 40 Qantas pilots participated in a three-hour condition that consisted of thirty minutes each for pre- and post-flight testing [that is, reaction time and subjective self-assessments] and briefing as well as two hours of flying. During flying sessions, participants completed a full flight including pre-flight checks, take-off, transit, descent, approach, and landing. During each flight, participants were presented with unique combinations of scenarios designed to test divergent skills that have been identified as being potentially susceptible to the effects of fatigue. As at March 2005, data collection is complete and analysis and reporting is still underway.

Field-based validations in progress

To ensure a cross section of environments are considered during the validation process, we have recently completed studies of two populations of shiftworkers that we have not previously studied. The populations used were rail terminal operators and rail-link truck drivers. These groups diverge both in the types of duties performed and in the compositional demographics of the workforce. Two separate studies utilising an identical protocol will be conducted.

A sample of close to fifty participants across the two studies was achieved. The study protocol required approximately two weeks of the participants' co-operation within their normal work environment. The two types of information collected were sleep/work patterns and the performance associated with their sleep/work patterns. As with the aviation validation above, both the objective PVT and subjective VAS methodologies were utilised. These measures will again be applied to the validation of the FAID model. Data collection is complete and analysis and reporting is underway.

Ongoing model development

The aim of the ongoing model development is to investigate additional factors such as those used as examples in section 2, which may improve model accuracy. Furthermore, an aim is to modify the current FAID model to minimise the impacts of the assumptions outlined in section 3.

In keeping with the possible additional factors provided in section 2, there are also others that may potentially improve the accuracy of the model. These factors [see below] will be

systematically included into the model calculations to determine their value. Examples of such factors include:

- Individual differences [including age],
- Time on task,
- Commute times to and from work,
- Sleep inertia following naps and other sleeps, and
- Alignment of predictions with epidemiological risk data.

At each stage of development, new versions of the model will be evaluated against existing fatigue/performance databases to determine whether or not they improve the predictive power of the current FAID fatigue model.

To address the assumptions discussed in section 3, the assumptions of the current model will be systematically replaced with assumptions that better reflect the current scientific beliefs. The current scientific beliefs are to be determined both by collected data and utilising peer-reviewed literature. In summary, the assumptions are likely to be addressed by:

- The incorporation of recent data on the phase shifting capacity of sleep/wake cycles,
- The experimentation with moving the performance trough that is nominally located at 0400 to 0600h to other time phases for specific populations,
- The updating of functions that determine the statistical distribution of sleep.
- The experimentation with various recovery curves for the value of naps.

It is proposed that these modifications will collectively increase the validity of the existing fatigue model for predicting fatigue levels associated with irregular hours of work in operational environments. Although no model can ever be perfect, we strongly believe that the previous and proposed work will continue to ensure that FAID is at least as accurate and practical as any available fatigue model.

References

[In chronological order - all available from the authors or the University of South Australia's Centre for Sleep Research on request]

- Dawson, D & Reid, K. (1997). Fatigue, alcohol and performance impairment. *Nature*, July 1997, 388:235.
- Fletcher, A & Dawson, D. (1997). A predictive model of work-related fatigue based on hours of work. *Journal of Occupational Health and Safety - Australia and New Zealand*, 13(5): 471-485.
- Fletcher, A. & Dawson, D. (1998). A work-related fatigue model based on hours-of-work. In: L. Hartley (Ed.) *Managing Fatigue in Transportation*, Oxford, Pergamon Press, 189-208.
- Fletcher, A. (1999). Measurement and management of work-related fatigue: Development and preliminary validations of a predictive model. Ph.D. Thesis, 1999, The University of South Australia.
- Fletcher, A., Roach, G.D., Lamond, N. & Dawson, D. (2000). Laboratory based validations of a work-related fatigue model based on hours of work. In: S. Hornberger, P. Knauth, G. Costa, S. Folkard (Eds.) *Shiftwork in the 21st Century: Challenges for Research and Practice*. Peter Lang, Frankfurt am Main, Germany.
- Dawson, D. & Fletcher, A. (2001). A quantitative model of work-related fatigue: Background and definition. *Ergonomics*, 44(2): 144-163.
- Fletcher, A. & Dawson, D. (2001a). A quantitative model of work-related fatigue: empirical evaluations. *Ergonomics*, 44(5): 475-488.
- Fletcher, A. & Dawson, D. (2001b). Field-based validations of a work-related fatigue model based on hours of work. *Transportation Research, Part F4*: 75-88.
- Fletcher, A., Lamond, N., van den Heuvel, C. & Dawson, D. (2003). Prediction of performance during sleep deprivation and alcohol intoxication by a quantitative model of work-related fatigue. *Sleep Research Online*, 5(2): 67-75.
- Roach, G.D., Fletcher, A. & Dawson, D. (2004). A model to predict work-related fatigue based on hours of work. *Aviation, Space and Environmental Medicine*, 75(3, Section II): A61-A69.