INDEPENDENT TRANSPORT SAFETY REGULATOR

Transport Safety Alert

www.transportregulator.nsw.gov.au

Transport Safety Alerts are published by ITSR under section 42L(2) of the *Transport Administration Act 1988* to promote the safe operation of transport services.

27 July 2010 | TSA no. 34

Use of bio-mathematical models in managing risks of human fatigue in the workplace

Background to safety alert

Many rail transport operators use bio-mathematical fatigue models to help manage fatigue associated with shift work.

This alert outlines some of the limitations of fatigue models drawing on findings of a review of computer-based fatigue models undertaken by ITSR. The purpose of this alert is not to criticise fatigue modelling but to alert the rail industry of potential limitations in the use of such modelling, and to provide strategies for incorporating fatigue modelling into a fatigue risk management regime.

Actions

- Rail transport operators that are using or intend to use a fatigue model to assist in fatigue risk management should consider the information provided in this alert that is presented in summary form below and in more detail in Attachment A of this alert.
- Rail transport operators should make the necessary adjustments in their practice of using bio-mathematical fatigue models to minimise over reliance on just the "results", for example, *scores*, in making fatigue risk management decisions.

The information in this alert is provided to inform in respect of the limitations of bio-mathematical models. In addition the information in this alert makes specific reference to the FAID model (Fatigue Audit InterDyne[1]) as it is the predominant model used by the rail industry in Australia.

All comments in regard to the properties and limitations of the FAID Model outlined in this alert and the attachment also need to be considered for applicability to any bio-mathematical fatigue model.

Key issues identified by the ITSR review

- Fatigue models are appropriate to be used as one tool to evaluate group work schedules to help identify how some aspects of fatigue exposure are distributed. However, models that are based on group average data should not be used as the sole basis for decisions on fatigue impacts on individual workers. Individual factors and the risk context should also be examined in each case.
- Generally current models only partially represent the factors that impact on fatigue and performance. Until models have a greater level of proven precision in terms of calibration and validity for particular

[1] *FAID* and *InterDyne* are registered trademarks of InterDynamics Pty Ltd

operational tasks, they cannot be solely relied upon to deliver 'rules' to be applied in fatigue risk management.

- Instructions supporting the use of such models are often unclear and need to be supplemented in order to provide better guidance to users.
- A FAID *score* of less than 80 does not mean necessarily that a person is not impaired by fatigue, or that that a work schedule is appropriate from a fatigue risk management perspective.
- When setting criteria for safety risk decision making rail transport operators should take into consideration the risk context and the basis of any recommended limits that may be associated with particular models.
- The sleep estimate output of FAID provides supplementary information to assess average opportunity for sleep. It provides a general indication of the impact of time-of-day factors on amount of sleep, based on group average data from a particular sample of workers. Rail transport operators that use FAID but do not currently use the sleep estimate should consider if there is benefit to integrating this output into their fatigue risk management processes.

For further information contact Simon Meiers, Director, Safety Advice on (02) 8263 7116 or Jennifer Alcock, Manager, Human Performance and Safety Promotion on (02) 8263 7194.

Len Neist

Chief Executive

Use of bio-mathematical models of fatigue

Rail safety law and managing fatigue-related risk

Rail safety laws in NSW require that rail transport operators implement a fatigue management program for all rail safety workers as part of an integrated safety management system.

The fatigue program must be risk-based according to the kind of tasks undertaken and scope of operations. Rail transport operators must consider a range of factors including: physiological factors (such as time-of-day influences on alertness and recovery, and length/frequency of breaks); work environment; rest environment; and social and psychological factors that may impact on performance and safety. Operators must monitor implementation of the fatigue program and evaluate its effectiveness.

The law also contains an overarching general duty for rail transport operators to ensure safety so far as is reasonably practicable. This general duty applies to the management of fatigue in the same way as any other risk to railway operations.

NSW rail safety legislation also contains minimum standards for hours of work for train drivers. These limits do not take into consideration time-of-day factors and do not limit night work. As such, compliance with these outer limits is not sufficient to satisfy the fatigue risk management requirements of the *Rail Safety (General) Regulation 2008* (clauses 11-13) or the general duty of the *Rail Safety Act 2008* for rail transport operators to ensure safety so far as is reasonably practicable.

This alert contains information on the limitations of solely using bio-mathematical model outputs as simple rules for decision making. Similar caution should apply if rail operators use legislated minimum standard shift limits as rules without assessment of the risk context including the applicability to particular operating circumstances.

Design and risk management of work schedules

Regardless of whether a fatigue model is used, work schedules should be designed and managed based on information from a number of sources one of which may be model outputs.

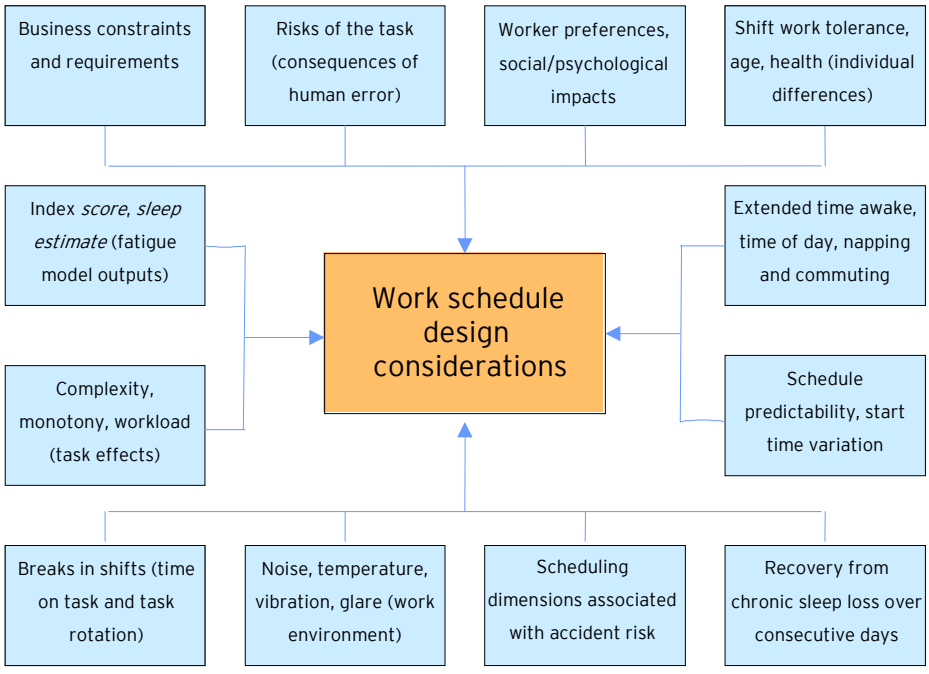

Figure 1: Examples of inputs for design of work schedules

Figure 1 shows a range of potential risk management considerations for design of working hours.

People who are responsible for design of schedules should be trained in fatigue management principles of shift work design. Fatigue is a complex problem to manage and specialist knowledge is often required. Fatigue model outputs should not be used to replace good practice (ergonomic) principles of schedule design.

The foundation of a fatigue management program is scheduling of work time to minimise accumulation of fatigue and maximise opportunity for recovery.

Poor schedule design and inadequate staffing levels cannot be compensated by requiring workers to estimate and disclose how much sleep they obtained or declare they are too fatigued. While these procedures may be part of a fatigue risk management system they have known limitations.

Risk management of night and early morning work

Fatigue occurs at all times of the day. However, if work is required to be performed at night and the early morning hours fatigue-related risk is much higher due to human biological processes that reduce alertness. The controls used to manage the tasks and workload of rail safety workers at these times is a critically important part of the fatigue management program.

People who are responsible for assessing the risks associated with varying tasks and workload of people undertaking safety critical tasks should understand how fatigue is likely to impact on task performance at night.

The safety system must contain elements to demonstrate that night work risks have been considered and reduced so far as is reasonably practicable. The fatigue risk assessment process should not be entirely delegated to workers who are likely to be fatigued themselves.

Use of bio-mathematical models

Fatigue models can be used as a component of a fatigue risk management system to help evaluate likelihood of fatigue associated with work schedules at the group level. The outputs can be used to help generally assess some time of day impacts that may not be addressed in legislated or industrial shift limits. When used according to their valid capability they can help identify fatigue problems that may not be evident using other quantitative measures.

Rail transport operators are not required to use a fatigue model to comply with rail safety legislation. However, operators who use models should obtain information on the appropriate use of the model relative to the current state of knowledge of human fatigue. This information will help determine how much a model can be relied on for different types of fatigue risk management decisions and what other information is needed.

Understanding the basis and limitations of models helps to understand what other information should be considered in order to take account of effects not considered by models. A number of cautions should apply when using models to make operational safety decisions.

These include:

- Use of a fatigue model is not in itself a fatigue risk management approach. A risk management approach can be achieved without using a model.
- Fatigue models are appropriate to use as one tool to help evaluate group rosters to help identify how aspects of fatigue exposure are distributed. Model outputs (for example, *scores*) should never be the sole basis for a safety risk management decision regarding work hours.
- Generally fatigue models are better at predicting performance when people are kept awake continuously. They are less effective at predicting the build up of performance impairment over many days of sleep loss and the process by which performance recovers after sleep restriction.
- Model outputs should not replace good practice principles of schedule design and should not be used as the sole indicator that a work schedule is appropriate or that a risk assessment is required.

- In addition to model outputs, organisations should take account of relevant data regarding aspects of work schedules that may be associated with accident risk.
- Model outputs that are based on averages should not be used to make decisions on individual workers, their fitness for duty, or to discount that fatigue was a factor in an incident.
- Analysis of the risk context for application of a model must include consideration of what fatigue effects the model incorporates, the underlying assumptions, uncertainties and limitations, and the results of testing relevant to particular tasks and operating conditions. This requires clear guidance from model developers and suppliers.
- Fatigue models do not generally account for task effects (for example, that some tasks are more sensitive to fatigue than others). Most models do not consider a range of other factors that impact on fatigue and performance such as workload, time pressure, work and team environment, skill level, experience, age, health, and home life.
- Operational people that use fatigue model outputs in safety risk management decisions must understand the appropriate use and limitations of any models used for safety risk management decisions. Appropriate instruction and training is required to ensure they are competent.

Use of the FAID model

Many NSW rail transport operators apply FAID as a tool to help manage risks associated with night work. ITSR found that many users are unsure of what the outputs mean and what fatigue effects are considered and what are not.

The ITSR review recommended improvements in the clarity of information available to FAID users regarding the basis for the different outputs, the results of calibration and validation studies and the cautions that should apply for operational safety applications.

Many of the limitations of FAID and other fatigue models can be overcome by use of additional information and application of good practice rostering principles that account for model limitations.

The following information outlines a number of cautions regarding use of FAID. It is intended to help rail transport operators understand the fatigue hazards (including physiological factors) considered by FAID and the limitations of using FAID *scores* as a rule in making safety risk management decisions.

The information provided focuses on the FAID model because it is the predominant model used by the Australian rail industry and other models were not as closely scrutinised by the ITSR review. This does not mean that the other models do not share the same issues. As many fatigue models have similar properties, all of the issues outlined should be considered for applicability to any bio-mathematical fatigue model.

The FAID scoring system and safety decision making

The FAID software and the model developers indicate that users must set their own limits using a risk based process. However, ITSR finds that rail transport operators in many cases are applying the general statements by the model developers in industry reports and articles on the validation of FAID[2,3] . These include that it can be generally stated that a FAID *score* of less than 80 points is consistent with a safe system of work. *Scores* above 100 are consistent with an unsafe system of work. *Scores* between 80 and 100 carry an element of risk and cannot be considered safe or unsafe unless the context of the work is known.

---

[2] Fletcher A. *A work-related fatigue model known as Fatigue Audit InterDyne(FAID), which uses hour-of-work as its input: Background validations, interpretation of results, assumptions and future work*. May 2003 (first revision August 2004; this revision March 2005). (Distributed with FAID v 2.0 330 software).

[3] Lamond N, Roach G, Darwent D, Dorrian J, Sletten T, McCulloch K, Eitzen G, Baker A, Fletcher A, Dawson D, Hussey F. Australia *Railways Shiftwork and Workload Study Phase Two Final Report* (undated) Centre for Sleep Research, University of South Australia.

- ITSR's review suggests that the research evidence to support these general statements about FAID *scores* in relation to operational safety outcomes is not strong.
- It has not been established if FAID *scores* can predict risk of incidents or accidents. There are published studies that provide some important insights into the effects of fatigue (reported in FAID *score* intervals) on aspects of train driving performance. However, the study design was not sufficient to validate precise threshold points in relation to safety outcomes such as *scores* of 80 and 100.
- The FAID *score high* point of 80 is said to be established by research that compared performance under conditions of continuous time awake with alcohol intoxication. The *score* of 80 was reported to be produced after 21-22 hours awake from 8 am when the level of performance impairment was equivalent to that produced at a Blood Alcohol Concentration (BAC) of greater than 0.05%.
- Fatigue associated with shift work involves cumulative effects from partial sleep loss over days and this has been found to have different effects than continuous time awake.
- Simple comparisons between fatigue and alcohol impairment that point to legal cut off points of BAC (for example, 0.05%) for motor vehicle drivers may have limited validity in other contexts because of the complexity of the different risks associated with fatigue and alcohol intoxication.
- Performance on some tasks is more sensitive to sleep deprivation than to alcohol intoxication. Also, performance under conditions of sleep deprivation differs considerably depending on the type of task – for example, the extent to which the task requires constant vigilance or complex thinking etc. This means that assessing and managing the impact of fatigue on particular safety tasks and workload demands is a critical part of fatigue risk management, regardless of the fatigue *score*.

Interpretation of FAID scores

- A FAID *score* (such as less than 80) does not mean that a work schedule is acceptable or that a person is not impaired at a level that could affect safety.
- The FAID *score* interval names of *low, moderate,* and *high* appear to be general qualitative descriptions. A person whose work hours yield a *score* in the *low* range can be fatigued. An example is on the first night shift when *scores* can be in the *low* range following a few days off but there may be fatigue impairment present if there is a long time awake before the shift.
- FAID *scores* should not be used in isolation of other relevant information in making safety decisions, particularly decisions on the acceptability of the design of a projected work schedule (for example, master) or actual working roster.
- FAID *scores* should not be used as the sole decision point to determine the acceptability of an individual work schedule, a person's fitness for duty or fitness to work overtime.
- FAID *scores* should not be used as the sole decision point to determine if a risk assessment is required for a particular situation.
- Informing individual workers of their FAID *score* for a work schedule is not an effective fatigue management control.
- FAID *scores* should not be used retrospectively to determine if an individual was fatigued at the time of an incident or as the sole criterion to determine if the work hours may have contributed to sleep loss.
- FAID *score* graphical displays such as *scores* over the course of a particular shift cannot be used to accurately pinpoint *high* risk times during the shift or to decide when fatigue countermeasures are needed. FAID outputs do not reflect extended time awake, time on a task, and the impact of task and workload on alertness and performance. These influences are likely to affect the profile of the shift, particularly in relation to accident risk.

The sleep estimate output of FAID

- The *sleep estimate* output is an important component of the FAID model as it provides easily understandable information for end users about the likely impact on sleep of the timing of shifts based

on group average data. The *sleep estimate* output of FAID helps supplement information from the FAID *score* output.

- A FAID *score* of under 80 does not necessarily mean that there is an adequate opportunity for recovery sleep. The FAID *score* output helps to assess some aspects of the accumulation of fatigue because it places a higher value on hours worked that are important for recovery sleep. However, the positive part of the FAID *score* declines during hours not worked occurs by a linear decay no matter what time of day the non-work period occurs. This means that it is difficult to determine the adequacy of a particular break by looking only at a FAID *score*.
- Supplementary information about the opportunity for sleep provided by non work time can be obtained by looking at the *sleep estimate* output of FAID as well as the FAID *score*. It shows that the sleep obtained during a quick daytime turnaround following a block of night shifts is likely to be very restricted although the FAID *score* may be less than 80. It is generally recommended that quick day time turnarounds between blocks of shifts (such as after a block of night shifts) should be avoided if there is a reasonably practicable alternative.
- Each FAID *score* considers a sliding window of seven days prior. The seven day cut off point creates a 'ceiling point' where a FAID *score* won't get any higher after seven days. This is shown in Figure 2. In these instances the FAID *sleep estimate* can be used to assess how sleep loss may continue to accumulate after seven days.

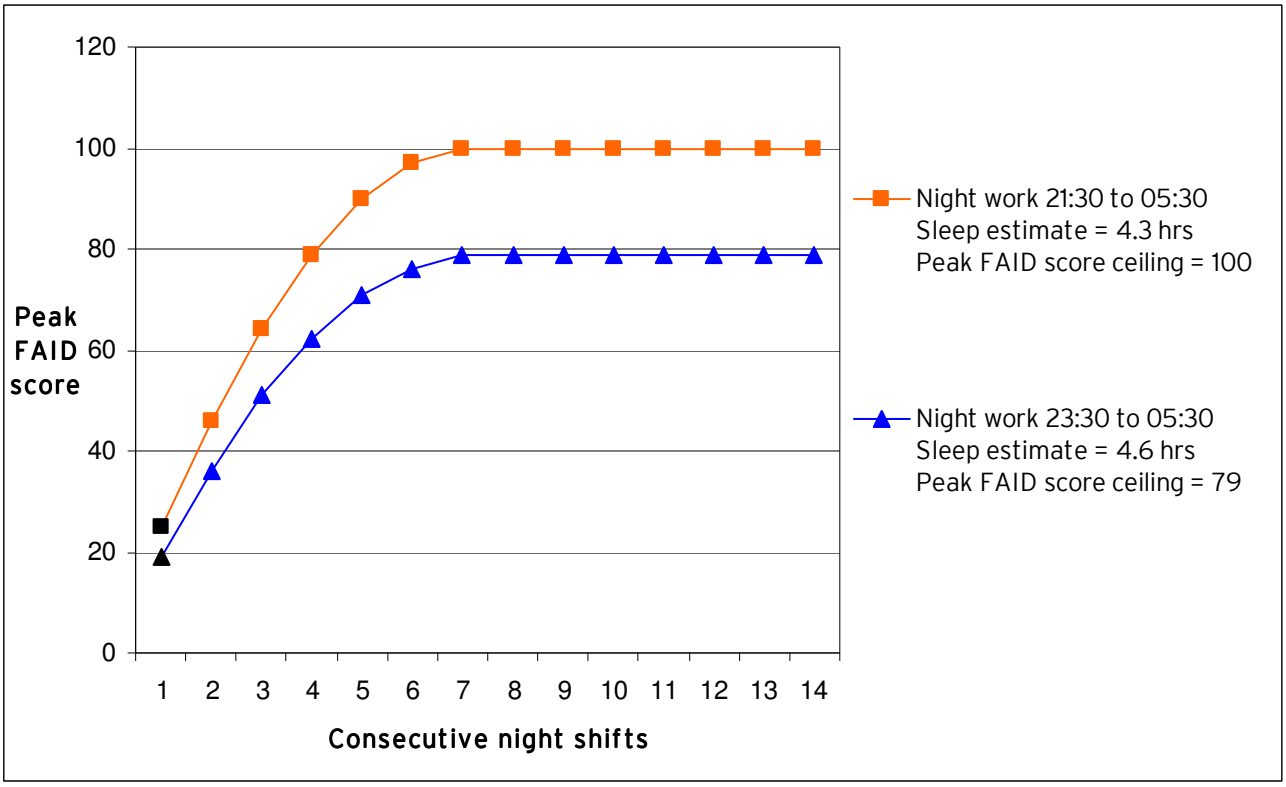

Figure 2: FAID *Scores* for 14 consecutive shifts 21:30 to 05:30 (■) and 14 consecutive shifts from 23:30 to 05:30 (▲). Both shift patterns suggest considerable sleep loss, although the FAID *scores* may be in the acceptable range depending on company procedures.

- Rail transport operators who are using FAID *scores*, but do not currently use the FAID *sleep estimate* output should consider integrating this output into decision making systems. However, caution should also apply to interpretation of the FAID *sleep estimate* as it appears to be based on average data from train drivers and may have less accuracy for other types of workers and particular shift work conditions.
- The default minimum sleep threshold settings in the FAID V2.0 software, of 5 hours in the previous 24 hours should not be interpreted as representing an adequate amount of sleep to perform safely.

There is some scientific uncertainty about use of minimum sleep thresholds and there is some supporting evidence for higher daily thresholds of 6 hours particularly for highly safety critical tasks. However, data collected from Australian rail safety workers has found significant proportions do not meet the default FAID sleep thresholds. For this reason work schedules should endeavour to optimise timing and duration of sleep, night work should be limited, and tasks undertaken at night should be risk-managed - so far as is reasonably practicable.

Use of FAID as a tool for analysis of group roster data

FAID *scores* and the FAID *sleep estimate* can be used retrospectively to help assess how some aspects of fatigue are distributed across the shift system. This sort of analysis is useful when there is a large workforce working shifts. The scoring intervals selected are very important for analytical purposes. Use of small intervals will show the full distribution of *scores* and reduce distortion that may occur (such as bunching of *scores* just under particular limits) if wider intervals are selected such as 40 to 80, 80 to 100 etc.

FAID *score* outputs should not be used as the only performance indicator to assess safety aspects of the shift system. Combined FAID data will reflect many of the limitations and assumptions that apply to use of FAID on individual work schedules. There is a range of other indicators that can be used to assess aspects of the effectiveness of work schedules and the fatigue management program including:

- monitoring of performance indicators associated with work schedules: for example, planned vs actual hours, total hours, time on task (breaks and task rotation), consecutive shifts, hours of night work, length of night shift, hours of overtime, breaks following night work, percentage of duties starting earlier than the previous duty, breaks of less than 12 hours, percentage of rests taken away from home, percentage of free evenings and week-ends
- monitoring of operational data, for example, monitoring of operational errors
- monitoring of absenteeism
- non-punitive fatigue reporting
- collection of sleep data and or self-reported sleepiness data
- surveys to assess psychological and social impacts of work schedules
- investigation of incidents to assess fatigue and other human factors including potential associations with work scheduling and workload
- analysis of schedules against dimensions associated with accident risk (for example, the UK Health and Safety Executive risk index).

There is a range of established sleepiness scales, shift work surveys and software tools that can assist in collection and analysis of this data.

Understanding more about the fatigue factors considered by FAID

Rail transport operators who are using FAID or any other fatigue model should ensure that they have clear procedures in how to use the model. This should include how to input data and interpret the outputs, what cautions should apply, and what other information is needed to make safety decisions.

Table 1 is a summary of key findings of ITSR's review of FAID. It is intended to help explain the extent to which FAID considers a range of fatigue factors. The information may help rail transport operators to understand the risk context including the limitations of using FAID as a rule in relation to individuals, or as the only tool to assess fatigue related risk. The information is based on a review of FAID 330 V2.0, published literature about the FAID model, independent expert review and evidence obtained during ITSR's compliance work.

Inevitably there will be new scientific findings that may impact on the validity of current models and point to new limitations or capabilities that need to be considered. There may be other issues and attributes associated with FAID than those outlined in the following material. The information presented should not

be used in place of the operator's own risk assessments, independent advice, and information from the model developers/suppliers.

Table 1: Some fatigue related factors and FAID outputs

Fatigue related factors	Extent to which they are reflected in FAID outputs
Time of day effects on alertness (circadian effects)	The FAID *score* output reflects time-of-day effects on alertness. Higher weight is given to the fatigue value of early morning hours and lowest fatigue value to late afternoon and early evening hours. The model assumes that this cycle is the same for every individual and does not change in response to different patterns of work schedules.
Extended time awake effects (for example first night shift)	The FAID outputs do not reflect time awake. An assumption of the model is that every hour not worked is counted as potential recovery sleep time. This means the FAID *score* for the first night shift is often in the *low* range if the night shifts follow more than two days off. But people often report being very tired on the first night shift because they may wake up at the normal time and have difficulty obtaining sleep during the day. A FAID *score* in the *low* range in association with a first night shift does not mean that fatigue impairment is not present.
Time of day effects on recovery sleep	The FAID *sleep estimate* is the component of the FAID model that helps to assess the opportunity for sleep provided by a break between shifts. The *sleep estimate* shows time-of-day effects on amount of sleep according to the timing of breaks between shifts. However, the *sleep estimate* is only indicative because it is based on average data from a study of train drivers and the software does not show the range of responses (for example, the confidence intervals). It may be less accurate for workers with a different age profile and shift work experience, or people who work particular shift patterns not well covered by the study. The *sleep estimate* does not consider particular sequences of shifts and individual responses and sleep strategies. The FAID *score* output is limited in its ability to assess the adequacy of recovery provided by a particular break between shifts because the FAID *score* focuses on the time of day that the work occurs. During non-work periods the positive fatigue *score*s accrued during work time discharge by a linear decay regardless of the time of day that the non-work period occurs.
Cumulative effects over days	Generally fatigue models cannot accurately predict the cumulative effects on performance and recovery of performance where there are many days of sleep restriction. FAID *score*s contain a cumulative fatigue function limited to a sliding window of seven days whereby the most recent hours contribute the most and then their value decays over a seven day period after which they don't count at all. The seven day limit and decay effect are assumptions of the FAID model. The sliding window and cut off point of seven days prior creates a ceiling point which limits how high the FAID *score* will go when there are more than seven consecutive shifts. This can easily be seen if the same shifts are entered in FAID for more than seven days. Examples of shifts that will never reach a FAID *score* of 80: • unlimited early morning shifts 05:45 to 13:45 (Peak FAID *score* 79, *sleep estimate* 6 hours in 24 hours)

	• unlimited night shifts 19:30 to 03:30 (Peak FAID *score* 79, *sleep estimate* 5.6 hours in 24 hours) • unlimited night shifts from 23:30 to 05:30 (Peak FAID *score* 79, *sleep estimate* 4.6 hours in 24 hours). Using the FAID *score* of 80 to distinguish between safe and potentially unsafe work schedules provides a limited picture in assessing the adequacy of recovery from cumulative effects if sleep is restricted over many days. If a *high* FAID *score* goes back to *moderate* (under 80) such as when there is a quick return (double-back) between the night and afternoon shift it does not mean that the person has recovered or that their performance is not impaired. A person's performance may take longer to recover from the disrupting effects of many consecutive shifts that impact on sleep. The *sleep estimate* output can help assess the potential extent of sleep loss over days and the need for longer breaks that provide opportunity for full uninterrupted night recovery sleeps.
Grogginess on waking (Sleep inertia)	FAID outputs do not reflect the period of impairment that occurs directly after waking. Effects of sleep inertia on workers who may be required to carry out safety critical tasks or make safety decisions soon after waking should be assessed separately.
Time on task	Effects of continuous time on a task without a break must be assessed separately. Published information on FAID indicates that nominally breaks should not be entered as non-work periods unless the break is at least four hours in duration and/or specific facilities are provided that are conducive to sleep. A FAID *score* can get lower with increasing time during the shift. This doesn't automatically mean that a person is getting less tired, or that breaks or other fatigue countermeasures are not needed.
Task and workload effects (vigilance tasks, effects of monotony, complexity etc)	FAID does not assess impact of the type of task or workload on alertness and performance, for example, a task that requires sustained attention and is monotonous or very complex or times of both. The effects on alertness and performance of these aspects should be assessed separately.
Age, social and psychological impacts on sleep (age, health, living situation, stress, competing priorities, other work etc)	FAID *scores* do not assess these factors in relation to individual workers. The FAID *sleep estimate* is based on data from train drivers and will reflect the real life impacts on the sample of drivers. Information should be sought on the characteristics of the sample population of the FAID *sleep estimate* as this may help assess the extent to which the *sleep estimate* data is relevant to other workers.
Commuting	Published information on the FAID *score* algorithm does not indicate that there is a specific commuting consideration reflected in the FAID *score* output. If this is the case, the longer the commuting period the less accurate the FAID *score* will become. The average commuting time in the group of train drivers that formed the basis of the FAID *sleep estimate* was about half an hour each way. If commuting periods are longer the estimate will be less accurate. Work related travel, for example, travel as passenger to and from remote worksites should be entered as work time for the purposes of the FAID *score* calculation. This is because FAID assesses every hour not worked as recovery time. The *sleep estimate* will over-estimate sleep likely to be obtained if these hours are not entered as work time in the model.

The rest environment	The FAID *score* does not assess the impact of the quality of a particular sleep environment. The FAID *sleep estimate* includes data from workers who were sleeping at home as well as away from home in a range of sleeping environments.
The work environment	FAID does not assess hazards of a particular work environment that may be associated with alertness and performance such as temperature, light, noise and vibration. These aspects need to be assessed separately.
Drugs (including caffeine) food, fluid intake effects on alertness	FAID does not consider the impacts of food, fluid or drug intake on alertness and performance.