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Getting Real About Biomathematical Fatigue Models

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Executive Summary

Scientific research over many decades has enabled biomathematical models (**BMMs**) of fatigue and performance to be developed to support fatigue risk management. Researchers and model developers have contributed various papers on the science behind BMMs and their applicability within the operational context. This paper attempts to provide a simple overview of the key scientific principles applied by most BMMs, and how models can be used to support fatigue hazard identification within a fatigue risk management framework.

BMMs model two or three processes, reflecting the current scientific understanding of the dynamics of the sleep-wake system and its effect on fatigue, performance and alertness. Models can be categorised as either one-step or two-step. One-step models require inputs for sleep-wake and work-rest data, whereas two-step models require input of only work-rest data. Two-step models estimate sleep-wake behaviour in step one and fatigue risk probabilities in step two. All models apply a two-step approach in predictive or planned analysis, as actual sleep-wake data is unavailable as a model input.

In the operational and fatigue risk management context, use of either one or two-step models is equally appropriate. Both provide fatigue risk probabilities associated with hours of work for population averages. Neither one-step nor two-step models provide absolute measures of fatigue or alertness for an individual (Dawson, Noy, Harma, Akerstedt, & Belenky, 2011). Models are only able to provide probabilistic, rather than accurate individual measures. As such, increasingly complex models that include more model inputs are unlikely to result in a marked difference in the fatigue management response within the operational context.

Adequate scientific validation ensures a BMM provides physiologically relevant outputs. Of arguably equal or greater importance is operational validation. Operational validation by way of comparative, trend, and correlation analysis with relevant operational safety and performance data is required, to ensure model applicability within a specific organisation's risk context.

Hazard identification under three analysis processes (reactive, proactive, and predictive analysis) can be supported by a BMM to monitor, evaluate, and analyse hours of work fatigue exposure. Demonstration of this is provided using FAID® (Fatigue Assessment Tool by InterDynamics). FAID is one model that has undergone extensive scientific validation in laboratory and simulation environments, and in operational settings, using multiple metrics of performance since the late 1990s.

Key Scientific Principles

BMMs currently model either two or three processes, reflecting the current scientific understanding of the dynamics of the sleep-wake system and its effect on fatigue, performance and alertness. A brief description of the two and three processes modelled is provided under **Figure 1**.

Processes Modelled	Description
Two-process	Based on Alexander Borbely's model on sleep-wake regulation posited in 1982, and includes: • Process S – homeostatic drive / pressure which is sleep-wake dependent, with sleep propensity increasing with time awake; and • Process C - sleep-wake independent, rising and falling with time of day and representing the circadian rhythm of core body temperature, sleep propensity, alertness and performance.
Three-process	In 1995, Akerstedt and Folkard extended Borbely's model to include consideration of sleep inertia (Process W). Sleep inertia is the performance impairment that occurs immediately upon awakening.

Figure 1 – Two and Three Processes Modelled

Both two and three-process models take into account the duration individuals have been awake (Process S), and the time of day relative to individuals' body clock (Process C) in assessing the impact on fatigue and performance for individuals. Where actual time awake and circadian timing information is not available then estimated or planned information would be used. Accurate, actual time awake and circadian timing information is rarely available in the operational environment, and what individuals plan to do, and what actually happens can be quite different. Models can therefore only provide an estimate of fatigue risk probabilities in real world settings.

A three-process model extends the two-processes to include sleep inertia (Process W). Research studies (Bruck & Pisani, 1998; Wertz, Ronda, Czeisler & Wright, 2006) indicate that sleep inertia is most significant when individuals are awakened during slow wave sleep. Tassi & Muzet (2000) have observed that in the absence of major sleep deprivation, the duration of sleep inertia rarely exceeds 30 minutes.[1] The impact of sleep inertia is particularly relevant in work situations where individuals may nap during breaks at work. It is important that individuals and organisations manage the risks associated with sleep inertia by applying work practices which limit the duration of a nap, and allows for an adequate recovery period before returning to work tasks. In the operational environment, whether a two or three-process model is used, organisations need to ensure work practices accommodate for sleep inertia.

Social, environmental, workload, and individual factors associated with fatigue and performance are not included in the two or three processes modelled. Until all significant, individual fatigue-related factors are able to be modelled, absolute and individual measures of fatigue are unable to be provided by BMMs. Only biological drivers of sleep-wake behaviour (based on population averages) are modelled, to provide generic population average predictions of performance and alertness.

[1] Bruck & Pisani, (1998) found that after one night of restricted sleep between 0200 and 0700, and 35 minutes after a 30 minute nap, performance was approximately 20% of optimum levels. Similar results were found by Wertz, et al. (2006).

BMMs have been categorised into two key modelling approaches, either one-step or two-step, depending on their required input (Kandelaars, Dorrian, Fletcher, Roach, and Dawson, 2005; Dawson et al, 2011). Brief descriptions of the one-step and two-step approaches are provided in **Figure 2** below.

Modelling Approach	Description
One-step approach	Work-rest data and sleep-wake behaviour (actual timing and duration of sleep including timing of the circadian system), used to predict fatigue and alertness.
Two-step approach	Work-rest data used to estimate sleep-wake behaviour (estimate timing and duration of sleep including timing of the circadian system), and subsequently fatigue and alertness.

Figure 2 – One and Two-Step Modelling Approach

As an example, FAID models two-processes and uses the two-step approach:

- Two-Step Approach: FAID uses work-rest data (hours of work as the model input), to estimate the sleep opportunity provided by the hours of work (Dawson et al, 2011).
- Two-Processes Modelled: The sleep opportunity or likelihood of recovery estimated by FAID (indicated by FAID Scores) is based on the duration and the circadian timing of work-rest periods (Lamond, van den Heuvel & Dawson, 2003).

Higher FAID Scores indicate lower likelihood of sleep opportunity or recovery, associated with the hours of work analysed by FAID. Laboratory and field studies have shown strong FAID Score correlations with objective vigilance and performance, and subjective sleepiness and tiredness measures (Fletcher 1999; Fletcher & Dawson, 2001a; Fletcher et al, 2003; Stewart & Abboud, 2005a; Dorian, Hussey & Dawson, 2007).

Comparing One-Step and Two-Step Models

Figure 3 below from the Centre for Sleep Research at the University of South Australia, cited in Dawson et al. (2011), compares one and two-step approaches to fatigue modelling.

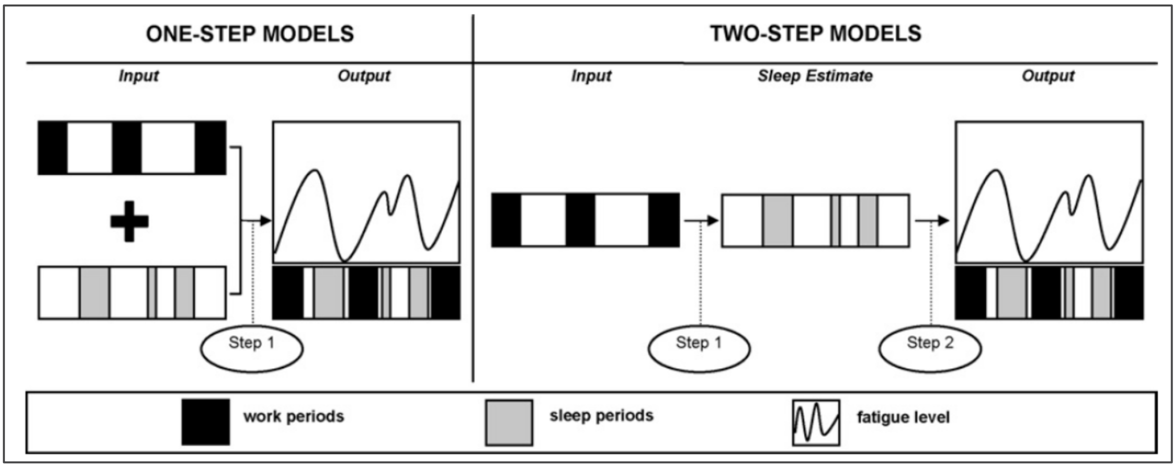


Figure 3 – One and Two-Step Approaches

Logically, one-step models would provide a better estimate of fatigue associated with sleep-wake behaviour than two-step models, as two-step model outputs are based on sleep estimates. According to Dawson et al. (2011), testing and validation of one-step models has occurred to a greater degree than two-step models. However, when actual sleep-wake data is unavailable as an input (e.g. in predictive analysis or work schedule planning), a one-step model is behaving as a two-step model, as estimated sleep data would need to be used (Civil Aviation Safety Authority, 2014).

One important application of a BMM in the operational context is in predictive analysis, to ensure planned work hours are within tolerable fatigue risk levels. In this context there is no advantage in using a one-step model. When analysing planned work schedules, where actual sleep-wake data is unavailable, all models are applying a two-step approach and estimating sleep-wake behaviour.

When carrying out retrospective or historical analysis, actual sleep data for an individual may be available (e.g. actigraphy data[2]) and entered into a one-step model. The one-step model would then simulate, based on the pattern of sleep entered, the biological drivers of sleep-wake behaviour (based on population averages). Subsequent outputs are generic population average predictions of performance and alertness. As can be seen, both the modelled drivers and resulting estimates are still based on population averages, even though in this instance simulated using an actual sleep pattern entered. Thus, similar to a two-step model, a one-step model is not in fact calibrated to predict an individual’s actual state of fatigue or alertness, despite individualised sleep data being included as an input.

Figure 4 below from Kandelaars (2006), cited in Dawson et al. (2011), demonstrates the potential differences in the outputs from a one-step model when sleep-wake data is available (one-step approach applied) or unavailable (two-step approach applied). The predicted alertness level outputs when applying one-step and two-step approaches, (indicated by darker and lighter lines graphed, respectively), were significantly different. This considerable variability is shown by the alertness level output using the two-step approach (indicated by the lighter line graphed) falling outside of the one-step ±95% confidence interval (grey band) on many occasions.

2 “Depending on the available resources, sleep diaries can be used alone to provide a measure of sleep timings, although the accuracy of self-reported sleep data may be limited. For example, a recent study (Lauderdale et al, 2009) found a poor correlation between reported and measured sleep durations (with persons sleeping five and seven hours over-reporting, on average by 1.3 (26%) and 0.3 (4%) hours respectively).” (Civil Aviation Safety Authority, 2014)

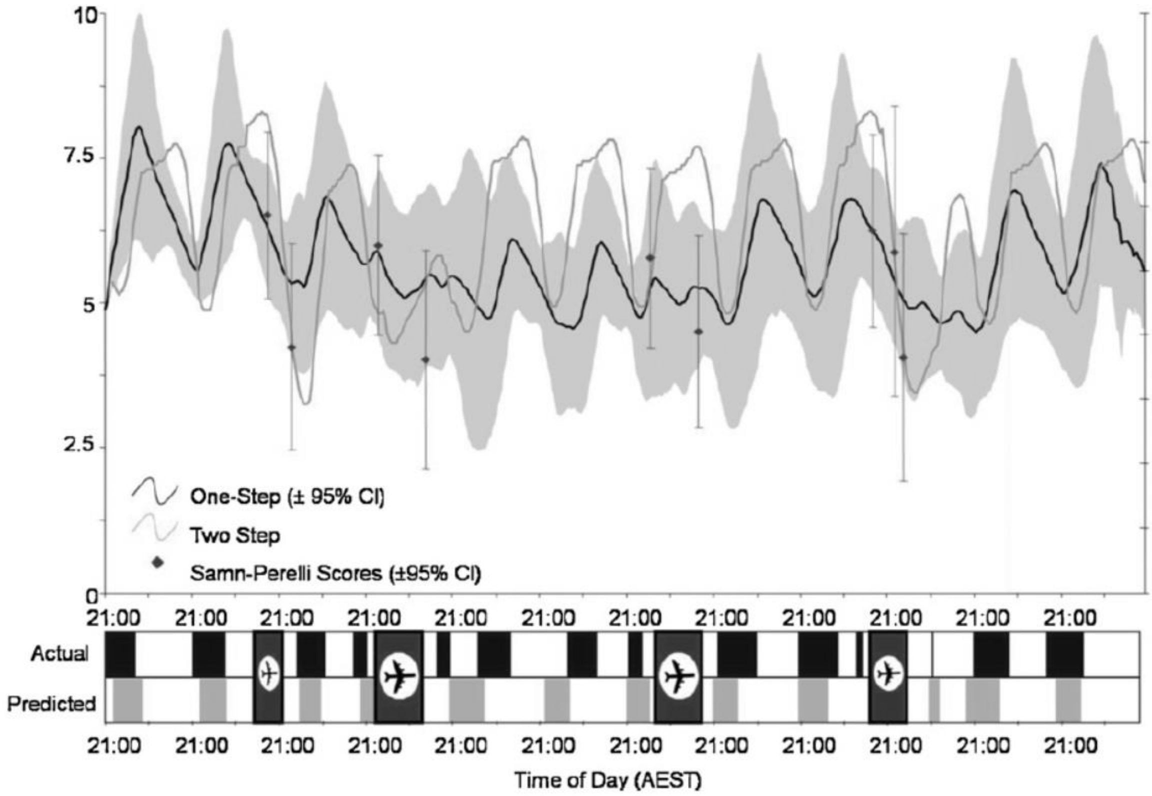


Figure 4 – Comparison of one and two-step approaches using data obtained from airline pilots (n=21) flying from Australia to Bangkok, London and Singapore. The figure (from Kandelaars, 2006) includes the alertness level outputs from one and two-step approaches, and self-rated Samn-Perelli fatigue ratings completed pre and post-duty periods.

Given the potential variability of outputs provided by a one-step model when sleep-wake data is available or unavailable, their model outputs when based on sleep-wake prediction should be reviewed with caution. Users of one-step models should not assume similar levels of output accuracy when sleep data is unavailable, to when it is available. Very little research has been published to indicate the statistical reliability of one-step model predictions of sleep-wake based on work-rest data (Dawson et al, 2011).

In summary, BMMs model either two or three processes, and all apply a two-step approach in predictive analysis. While theoretically one-step models may provide greater accuracy in retrospective analysis when actigraphy data is available, their outputs are only probabilistic indications and relevant to average populations. In the operational and fatigue risk management context, both one and two-step models are equally valid, as both provide fatigue risk probabilities for population averages. Neither one-step nor two-step models provide absolute measures of fatigue or alertness for an individual.

Model Accuracy

BMMs apply scientific principles developed through empirical research on sample populations. This research provides indications, probabilities and reference points against the sample population, and not necessarily definitive answers or conclusions. Hence, model outputs are unable to provide greater accuracy than probabilistic indications, relevant to average populations. With this limitation in mind, BMMs can provide a way to incorporate circadian and sleep-wake systems as part of fatigue hazard identification.

When reviewing prospective or planned work schedules using a BMM, the BMM indicates whether the hours of work are likely to contribute to reduced alertness and performance. Similarly, when work hours are reviewed retrospectively, an indication of historical hours of work related fatigue exposure is provided. Within a fatigue risk management framework, where focus is on the balance of exposure and controls, BMMs need only (and can only) provide an indication of relative fatigue exposure or fatigue risk probabilities, rather than actual measures of fatigue or definitive 'go' / 'no go' results.

In the instance where a BMM allows the option for individual inputs such as habitual sleep duration and chronotype (an individual's tendency to be morning types or evening types), care needs to be taken that outputs are not interpreted as providing actual measures of fatigue. While this additional information may be useful as part of a risk assessment, it is unable to refine a BMM's estimate or output enough to provide an individual measure of fatigue. Other individual factors would need to be considered, such as social, environmental, workload impacts, the difference in weighting of factors, as well as the significance of the interaction of multiple fatigue contributing factors on an individual, etc.

Models are only able to provide probabilistic rather than accurate individual measures. As such, increasingly complex models that include more model inputs are unlikely to result in a marked difference in the fatigue management response within the operational context.

Model Validation

A BMM should have three components in its development and validation to ensure its applicability within an operational setting:

- That it is based on sound scientific research;
- Has undergone extensive scientific validation; and
- Continues to be validated within the operational environment.

The last two points are discussed below using FAID as an example.

Scientific Validation

Adequate scientific validation ensures the BMM provides physiologically relevant outputs, such as sound predictions of fatigue and performance measures. For example, **Figure 5 & Figure 6** below shows a very strong FAID Score relationship with multiple fatigue and performance measures. Linear regression (R^2) values of 0.85 for psychomotor vigilance task (**PVT**) lapses, and 0.94 for mean daily multiple sleep latency test (**MSLT**) results indicate a very strong relationship. These R^2 values indicate 85% and 94% of the variance in PVT, and MSLT results, respectively, are accounted for by the predicted change in FAID Score.

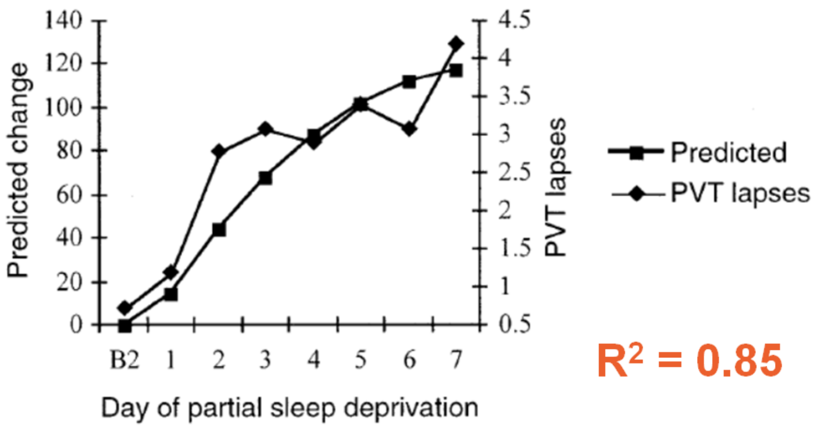


Figure 5 – Mean (for testing at 10:00, 16:00 and 22:00 hours) relative performance on a 10-min visual psychomotor vigilance task (PVT) for 16 participants across the final baseline day (B2) and 7 days of partial sleep deprivation (mean sleep 5h) against predicted relative change (Fletcher & Dawson, 2001a).

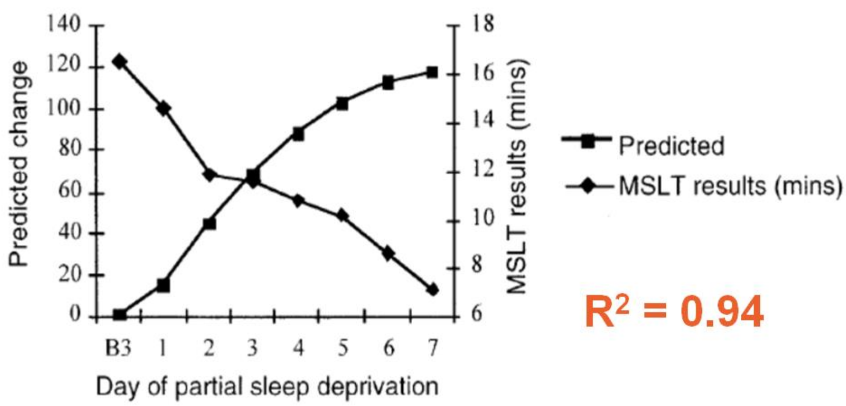


Figure 6 – Mean daily multiple sleep latency test (MSLT) duration across the final baseline day (B3) and 7 days of partial sleep deprivation (mean sleep 5h) against predicted relative change (Fletcher & Dawson, 2001a). Note: There is an inverse relationship between FAID Scores and MSLT results.

Figure 7 below shows FAID Scores are moderately to strongly related to the performance measures as a result of sleep deprivation. Polynomial regression (R^2) values indicate that FAID modelling predicted 47% to 89% of the variance in the range of simple to complex tasks testing speed and accuracy.

	Measure	Regression Equation	R^2	*p*
Y_1	GRT Mean Response	$0-0.12\ x_{FAT} + 0.01\ x_{FAT}^2$	0.68	<0.0001
Y_2	GRT Error Rate	$0-0.07\ x_{FAT} + 0.0004\ x_{FAT}^2$	0.89	<0.0001
Y_3	TRK Score	$0+0.5\ x_{FAT} - 0.008\ x_{FAT}^2$	0.47	0.0004
Y_4	VIG Mean Response	$0-0.04\ x_{FAT} + 0.003\ x_{FAT}^2$	0.84	<0.0001
Y_5	VIG % Correct	$0-0.01\ x_{FAT} - 0.0004\ x_{FAT}^2$	0.74	<0.0001
Y_6	SSC % Correct	$0-0.05\ x_{FAT} + 0.0002\ x_{FAT}^2$	0.55	<0.0001

Figure 7 – Polynomial regression equations R2 and significance (p) for performance measures with FAID Scores as the dependent measure (Fletcher et al, 2003). Note: Performance measures include Simple Sensory Comparison (SSC), Vigilance (VIG), Unpredictable Tracking (TRK), and Grammatical Reasoning (GRT).

Similarly, in **Figure 8** below, polynomial regression (R^2) values indicate that 27% to 98% of the variance for the same range of tests is accounted for by the predicted change in Blood Alcohol Concentration (**BAC**). These results were used by Fletcher et al (2003) to equate performance impairment at various FAID Scores with comparable levels of impairment due to alcohol intoxication.

	Measure	Regression Equation	R^2	*p*
Y_1	GRT Mean Response	$0-165.0\ x_{BAC} + 2705.6\ x_{BAC}^2$	0.74	<0.0001
Y_2	GRT Error Rate	$0-41.1\ x_{BAC} + 221.4\ x_{BAC}^2$	0.80	0.0003
Y_3	TRK Score	$0+27.7\ x_{BAC} - 1816.2\ x_{BAC}^2$	0.76	0.0008
Y_4	VIG Mean Response	$0+110.4\ x_{BAC} + 853.9\ x_{BAC}^2$	0.98	<0.0001
Y_5	VIG % Correct	$0-53.9\ x_{BAC} + 243.0\ x_{BAC}^2$	0.96	<0.0001
Y_6	SSC % Correct	$0-101.8\ x_{BAC} + 444.2\ x_{BAC}^2$	0.27	0.21

Figure 8 – Polynomial regression equations R2 and significance (p) for performance measures with BAC as the dependent measure (Fletcher et al, 2003). Note: Performance measures include Simple Sensory Comparison (SSC), Vigilance (VIG), Unpredictable Tracking (TRK), and Grammatical Reasoning (GRT).

Multiple validation studies (Fletcher 1999; Fletcher & Dawson, 2001a; Fletcher et al, 2003; Stewart & Abboud, 2005a; Dorian et al, 2007) have shown that higher FAID Scores do strongly indicate higher probability of fatigue and performance impairment associated with hours of work. In particular, some studies (Fletcher & Dawson, 2001; Fletcher et al, 2003) indicate that impairment associated with FAID Scores of approximately 80 are strongly correlated with the impairment associated with blood alcohol concentrations of 0.05% or more. How this fatigue exposure relates to performance and safety in the work context requires validation within the operational environment.

Operational Applicability

Good scientific or laboratory validation is important, and once completed satisfactorily should not be continually required. Of arguably equal or greater importance is operational validation. It is essential that a BMM's outputs are reviewed in conjunction with the safety and performance measures specific to the organisation, to ensure appropriate and contextual application. Otherwise, a BMM's outputs can only provide relative estimates to compare one work pattern against another, without any reference to how differences in fatigue exposure may be associated with safety or performance outcomes.

In a study of 100 train drivers driving 50 locomotives with data loggers on board, Dorian et al. (2007), investigated changes in driving parameters associated with work schedules with different fatigue exposure levels (or Peak FAID Scores). Three exposure levels were categorised as part of the study:

- Low, representing work hours associated with FAID Scores of less than 65;
- Moderate, representing work hours associated with scores between 65 and 80; and
- High, representing scores of greater than 80.

Some of the key results are shown below.

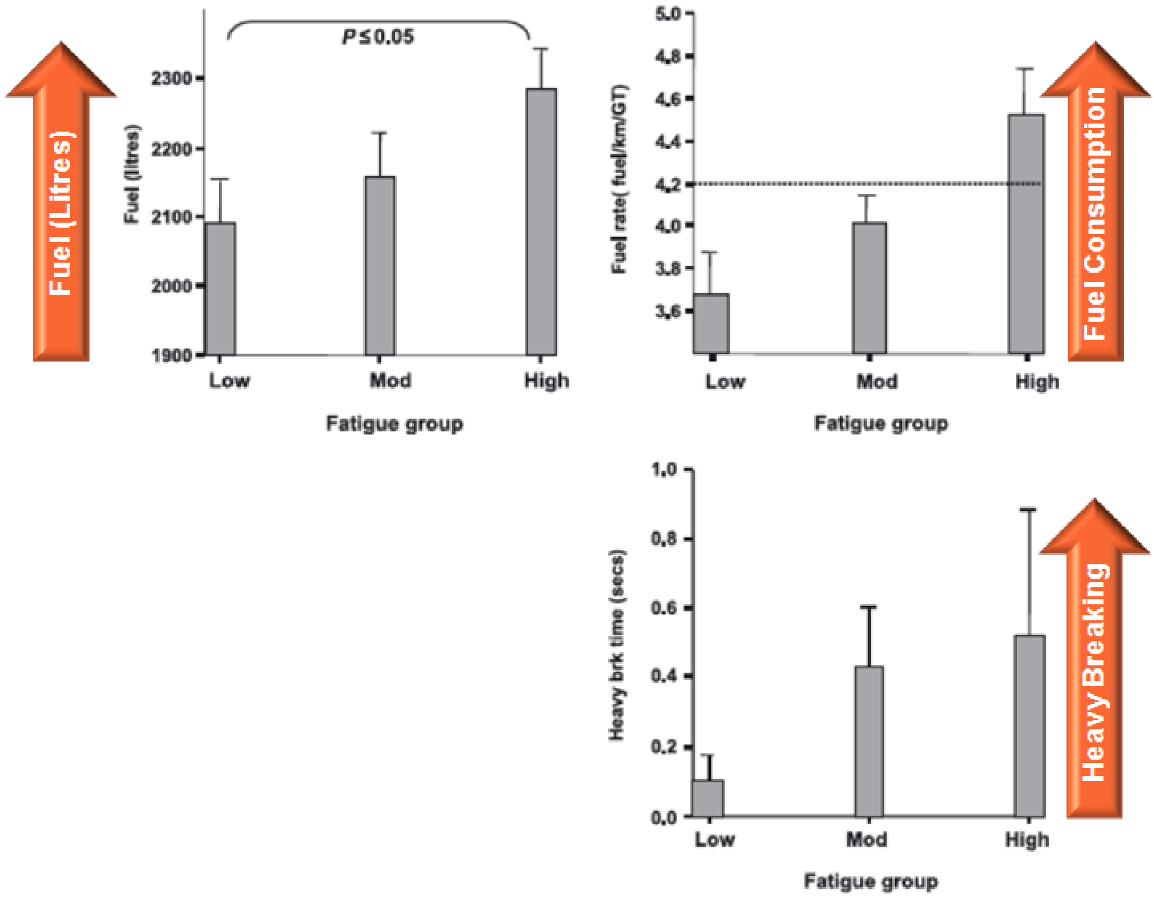


Figure 9 - Train driving parameters at low, moderate and high operator FAID Score categories (fatigue group). Fuel consumption (L), fuel rate (L km^{-1} GT^{-1}), and heavy brake violations in each fatigue group (Dorian et al. 2007). Note: The dashed line in the above top right graph indicates the target maximum fuel rate (specified by the rail operator for the corridor reviewed) in which the High group exceeds.

Dorian et al. (2007) found that statistically significant relationships were associated with fuel consumption, heavy brake violations and higher FAID Scores. The dashed line in the top right graph of **Figure 9** above indicates the target maximum fuel rate, which the High group exceeded. The results indicated that train drivers in the High group, with working hours associated with Peak FAID Scores of greater than 80 were more likely to perform heavy brake violations and exceed the target maximum fuel rate. These are operationally useful BMM reference points, which can be used to support the management of fatigue-related risks associated with hours of work, and in this case also reduce fuel consumption and heavy brake violations.

It is similarly possible to review other performance and safety metrics such as absenteeism, error and incident rates, etc. in conjunction with FAID Scores. **Figure 10** below shows a significant increasing trend in incident rates (incidents per million hours worked) with increases in FAID Scores of greater than 40 for one organisation.

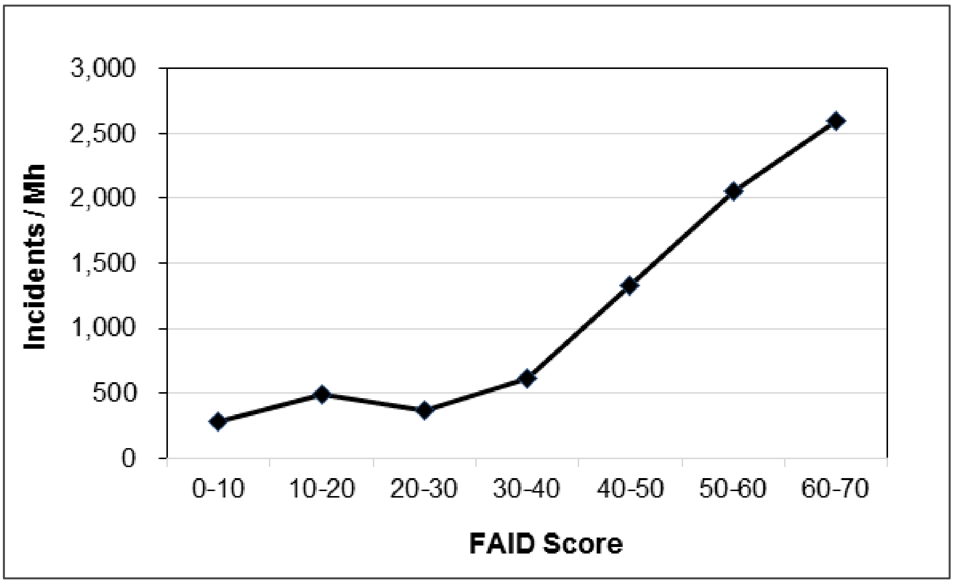


Figure 10 – Increasing trend in incident rates (incidents per million hours worked) with increases in FAID Scores of greater than 40 for one organisation

The incident rate trend suggests the likelihood of an incident can be high, despite FAID Scores associated with this organisation's hours of work being relatively low. Hence, FAID Score benchmark targets could be set relatively low, (e.g. high Target Compliance to a FAID Score benchmark / FAID Fatigue Tolerance Level as close as possible to 40), as one possible control to support risk management for their operations.

It can be seen that low BMM results may not necessarily indicate low fatigue-related risks in the operational context. Operational validation by way of comparative, trend, and correlation analysis with relevant operational safety and performance data is required to ensure model applicability within a specific organisation's risk context.

Fatigue Hazard Identification

Put simply hazard identification is the process of detecting an exposure or potential loss situation within a system. Many regulatory frameworks around the world recognise fatigue as an exposure.

In Australia, the national work health and safety statutory body, Safe Work Australia, requires organisations to identify and manage factors that could contribute to and increase the risks associated with fatigue. Fatigue risk management requirements include examining work practices and systems of work associated with working hours.

The International Civil Aviation Organisation (**ICAO**) standards on Fatigue Risk Management Systems (**FRMS**) require operators to develop and maintain three processes for fatigue hazard identification:

- **Reactive:** Identifying the contribution of fatigue hazards to reports and events associated with potential negative safety consequences in order to determine how the impact of fatigue could have been minimised.
- **Proactive:** Identifying fatigue hazards within current flight operations.
- **Predictive:** Identifying fatigue hazards by examining crew scheduling and taking into account factors known to affect sleep and fatigue and their effects on performance.

FAID outputs are explained in **Figures 11, 12 & 13** below, to provide guidance on how fatigue hazard identification under the three ICAO analysis processes can be supported by a BMM. FAID technology in the form of FAID Standard, FAID Roster Tool and FAID Business Wide versions (including Time Zone version) provides users the ability to carry out monitoring, evaluation, and analysis of hours of work fatigue exposure.

For further information on FAID refer to 'What You Need To Know About FAID' under the following link: http://www.interdynamics.com/fatigue-risk-management-solutions/resources-and-media/

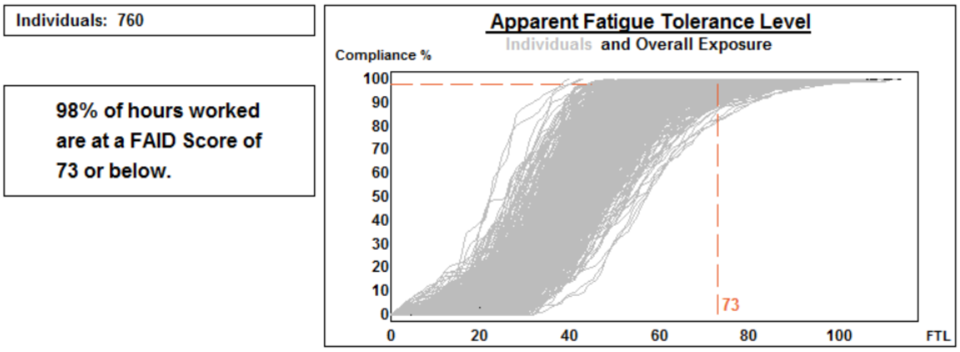
Reactive Analysis

Type of Analysis	Description

Reactive Analysis: Retrospectively reviewing hours of work in response to fatigue reports, a review of an event or incident, or an audit. This analysis gives consideration to whether the worked hours were likely to have contributed to reduced alertness and performance.

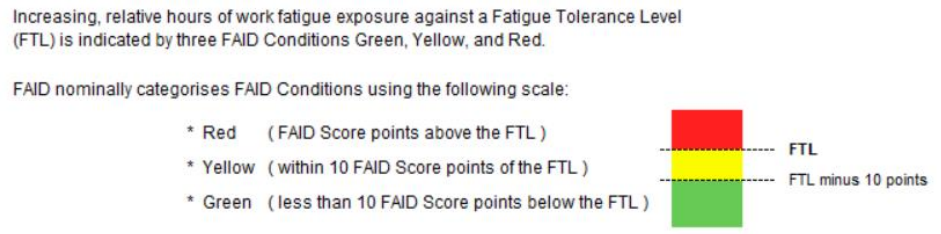
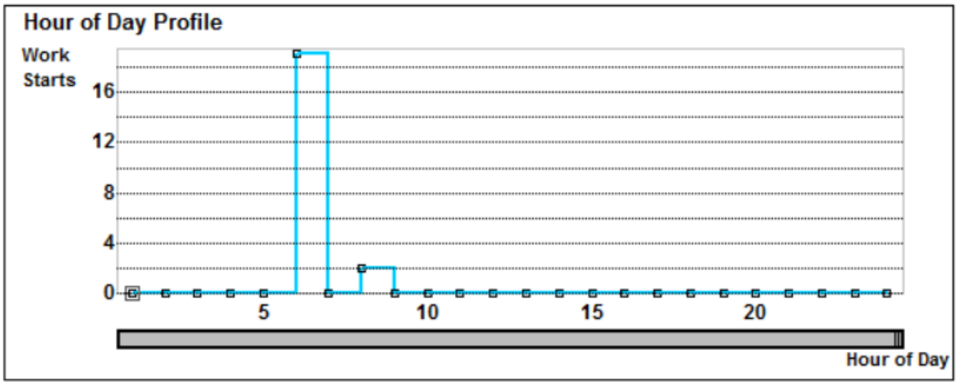
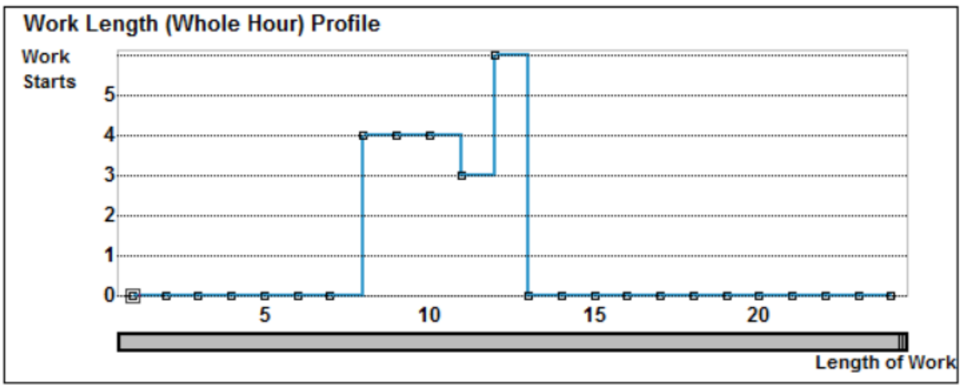
Current hours of work fatigue exposure tolerated by the organisation

FAID can be used to review 6-12 months (or another suitable period) of historical hours of work to determine the current hours of work fatigue exposure tolerated by the organisation. See below output from FAID Standard, Time Zone, Roster Tool and Business Wide versions providing the 98th percentile (or percentile specified by the user) FAID Score figure.



This 98th percentile figure (in this example) can be used for reactive analysis to ascertain the number of instances prior to an event that the hours went above this figure. That is, the number of times exceptional or unforeseen circumstances occurred (indicated by hours of work with FAID Scores greater than the 98th percentile figure), and for how long (shown by FAID Condition Red column below).

Start	End	FAID Condition Green	FAID Condition Yellow	FAID Condition Red	Peak FAID Score	Non-Work	Work
15 Jul 11 0715	15 Jul 11 1545	8hr 30min			54	15.5	8.5
27 Jun 11 1400	27 Jun 11 2200	8hr 0min			30	72.0	8.0
28 Jun 11 1400	28 Jun 11 2200	8hr 0min			34	16.0	8.0
29 Jun 11 0900	29 Jun 11 2200	13hr 0min			45	11.0	13.0
30 Jun 11 0600	30 Jun 11 1400	8hr 0min			62	8.0	8.0
1 Jul 11 2200	2 Jul 11 0600	6hr 1min	49min	1hr 11min	79	32.0	8.0
2 Jul 11 0600	2 Jul 11 1400	3hr 37min	2hr 16min	2hr 7min	82	0.0	8.0
3 Jul 11 0600	3 Jul 11 1400	3hr 24min	2hr 9min	2hr 27min	86	16.0	8.0
4 Jul 11 0600	4 Jul 11 1400	3hr 23min	2hr 8min	2hr 29min	86	16.0	8.0
5 Jul 11 0600	5 Jul 11 2200	10hr 7min	3hr 26min	2hr 27min	85	16.0	16.0
7 Jul 11 0600	7 Jul 11 2200	12hr 40min	2hr 42min	38min	74	32.0	16.0
9 Jul 11 0530	9 Jul 11 1900	11hr 9min	2hr 21min		68	31.5	13.5
12 Jul 11 2200	13 Jul 11 0600	8hr 0min			51	75.0	8.0
13 Jul 11 1400	13 Jul 11 2200	8hr 0min			41	8.0	8.0
14 Jul 11 1000	14 Jul 11 2200	12hr 0min			49	12.0	12.0

Type of Analysis	Description
	 In this case the FAID Score benchmark figure (Fatigue Tolerance Level / FTL) was set at 73 to review the number of times exceptional / unforeseen circumstances occurred which were greater than this 98th percentile figure and for how long (shown by the FAID Condition Red column above).
Number of early work starts & work period durations leading up to an event	The number of early work starts, and the typical work period / duty durations, for the weeks leading up to an event can be reviewed. See below outputs from FAID Standard, Roster Tool and Business Wide versions.  

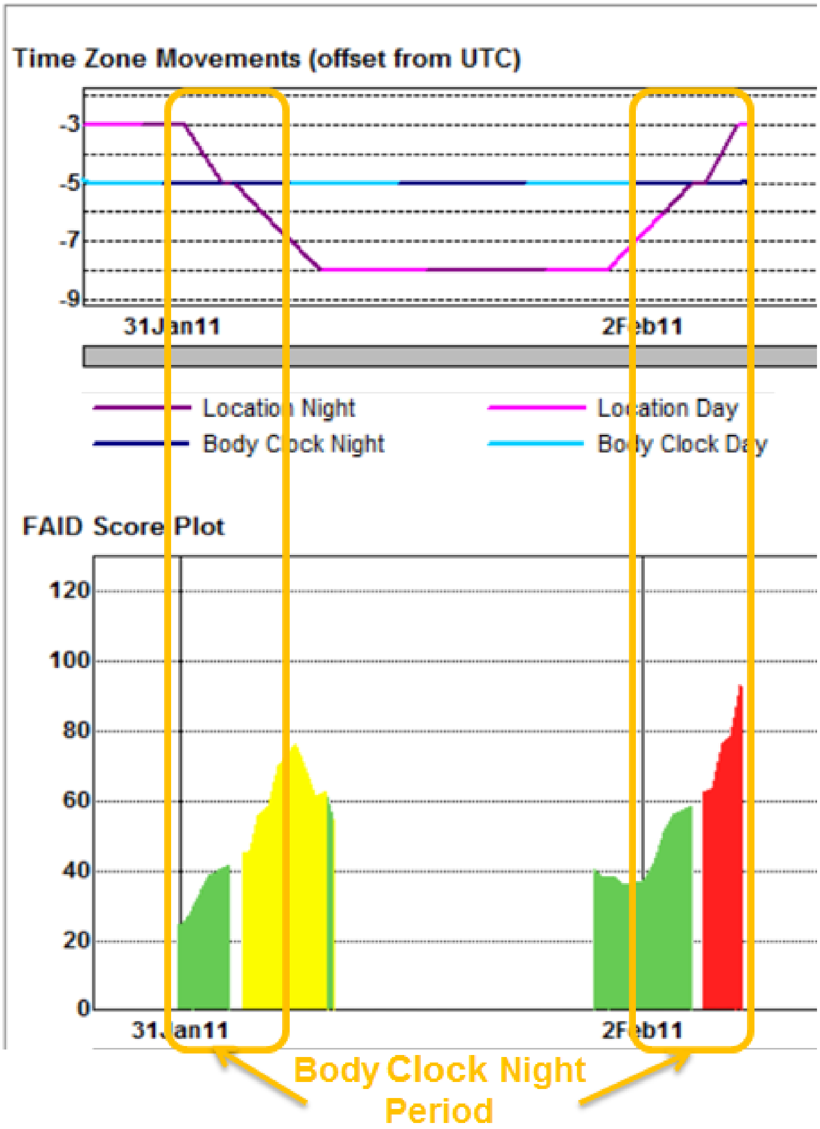
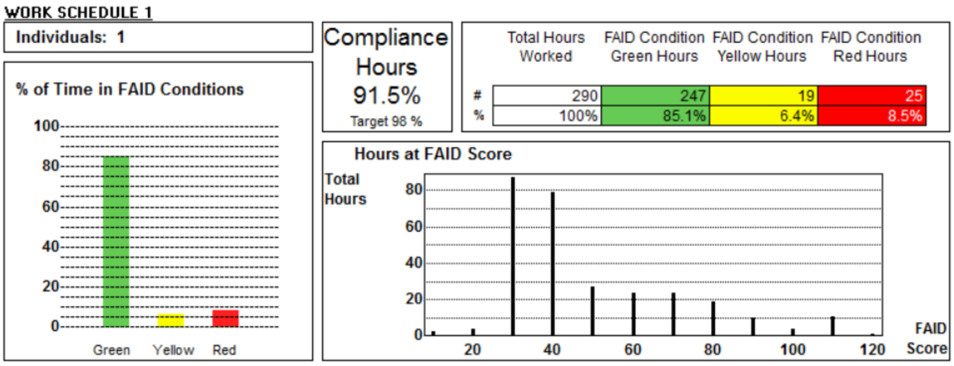
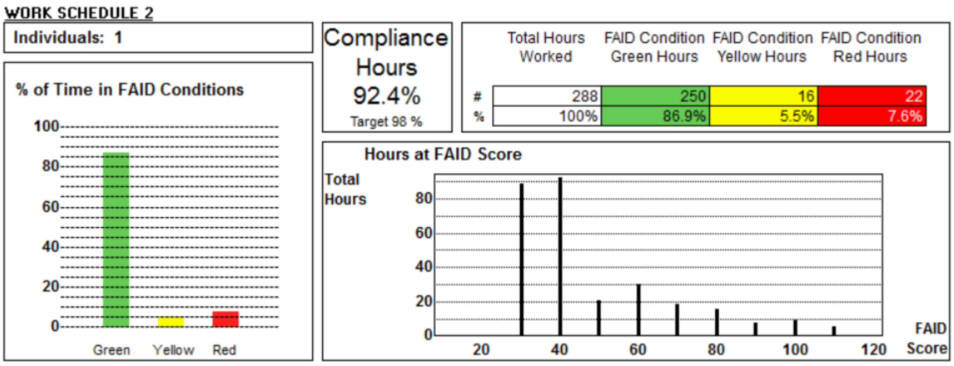
Type of Analysis	Description
Number of work periods during body clock night leading up to an event	Time Zone related outputs can be used to review the number of occurrences of work / duty periods during body clock night leading up to an event. 

Figure 11 – Reactive Analysis

Proactive Analysis

<table>
<tr><th>Type of Analysis</th><th>Description</th></tr>
<tr><td colspan="2">Proactive Analysis: Regular monitoring and review of planned and actual hours of work to identify relatively higher exposure work schedules and hours of work. This information can be used to refine shift design and associated limits, improve future shift planning, and identify business process changes required to ensure hours of work fatigue exposures are within tolerable risk levels.</td></tr>
<tr><td>Compare planned and actual hours of work</td><td>Compare planned and actual hours of work. See below outputs from FAID Standard, Time Zone, and Roster Tool versions, comparing Work Schedule 1 & 2 (Actual and Planned hours of work).
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Type of Analysis	Description
Identifying higher fatigue exposure work patterns / pairings for risk improvement action consideration	Comparative FAID Key Risk Indicators can also be reviewed. For example, sort 'Name' by Compliance %, ascending, to identify individuals / work patterns with least compliant hours (highest fatigue exposure, from an hours of work perspective) at the top of the table. Compliance is to FAID Score benchmarks (Fatigue Tolerance Levels - **FTLs**) chosen as an outcome of a Fatigue Hazard Analysis risk assessment process.

Compliance Work Schedule 1

	Name	Total Hours	Total Hrs> FTL	Compliance (%)	FAID Condition Green %	FAID Condition Yellow %	FAID Condition Red %	Peak FAID Score
1	D10035_17	131.8	14.6	88.9	81.1	7.8	11.1	80
2	D10040_26	189.6	19.7	89.6	80.0	9.6	10.4	86
3	D10031_33	143.3	13.1	90.9	84.9	6.0	9.1	81
4	D10033_27	141.2	12.4	91.2	86.9	4.3	8.8	77
5	D10042_20	129.5	8.4	93.5	85.1	8.4	6.5	86
6	D10041_24	170.7	10.4	93.9	88.1	5.8	6.1	76
7	D10034_16	127.3	7.2	94.3	85.2	9.1	5.7	83
8	D10043_15	163.9	7.6	95.4	90.2	5.2	4.6	74
9	D10037_18	151.3	5.9	96.1	87.4	8.7	3.9	81
10	D10044_22	168.9	5.9	96.5	92.9	3.6	3.5	74
11	D10032_29	170.5	5.7	96.6	88.8	7.8	3.4	74
12	D10021_55	40.8	1.4	96.7	84.3	12.3	3.3	71
13	D10027_63	85.8	2.7	96.8	85.7	11.1	3.2	68

Compliance Work Schedule 2

	Name	Total Hours	Total Hrs> FTL	Compliance (%)	FAID Condition Green %	FAID Condition Yellow %	FAID Condition Red %	Peak FAID Score
1	D10040_26	216.6	32.2	85.1	75.9	9.3	14.9	91
2	D10035_17	145.1	17.5	87.9	79.5	8.4	12.1	82
3	D10042_20	144.3	17.1	88.1	80.2	7.9	11.9	93
4	D10027_63	97.4	9.6	90.1	80.5	9.6	9.9	86
5	D10031_33	159.7	14.9	90.7	83.6	7.1	9.3	82
6	D10033_27	151.9	14.1	90.7	86.3	4.3	9.3	77
7	D10041_24	181.5	12.8	93.0	88.0	5.0	7.0	76
8	D10034_16	135.2	9.5	93.0	81.0	11.9	7.0	88
9	D10021_55	45.7	3.2	93.1	73.4	19.6	6.9	72
10	D10037_18	171.0	11.5	93.3	82.7	10.6	6.7	86
11	D10043_15	185.2	12.2	93.4	85.9	7.5	6.6	79
12	D10032_29	188.9	11.5	93.9	85.5	8.5	6.1	80
13	D10045_31	142.4	8.1	94.3	88.6	5.8	5.7	72

In the instance the 'Name' column represents a work pattern including flight duty pairings, than the above output can be used to identify work patterns / pairings with least compliant hours or the highest fatigue exposure (from an hours of work perspective) at the top of the table.

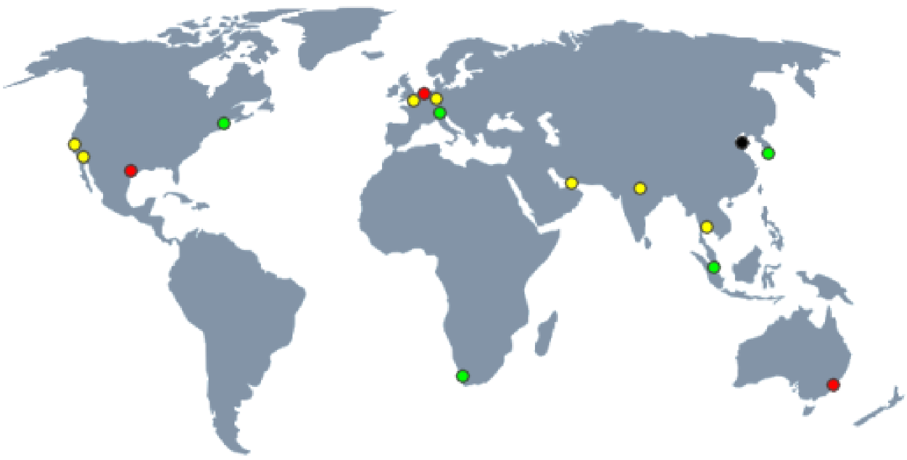
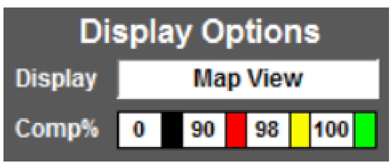
Where an organisation has not chosen a FAID Fatigue Tolerance Level, the 98th percentile figure (or 'Apparent FTL') of all pairing configurations (or work patterns) analysed can be used as the FAID Fatigue Tolerance Level can be used to these work patterns. The above FAID Key Risk Indicators report (sorted by ascending Compliance %) can then be used to identify the highest fatigue exposure pairing configurations (or work patterns) from an hours of work perspective for risk improvement action consideration.

<table>
<tr><th>Type of Analysis</th><th>Description</th></tr>
<tr><td>Review how long work periods are in FAID Condition Red</td><td>The FAID Exposure Log output (which shows all shifts that have fallen into FAID Condition Red) can be used to review the work pattern or pairing of interest, to ascertain how long the work period is in FAID Condition Red (or above the set Fatigue Tolerance Level). This information can be reviewed as part of a risk assessment to ascertain whether risk improvement action is required.

FTL EXPOSURE LOGS
<table>
<tr><th>Name</th><th>UTC Start</th><th>Origin</th><th>UTC End</th><th>Destn</th><th>FAID Condition Green</th><th>FAID Condition Yellow</th><th>FAID Condition Red</th></tr>
<tr><td>D10000_39</td><td>14 Jan 11 2305</td><td>JFK</td><td>15 Jan 11 0620</td><td>LHR</td><td>5hr 7min</td><td>1hr 17min</td><td>51min</td></tr>
<tr><td>D10000_39</td><td>15 Jan 11 0620</td><td>LHR</td><td>15 Jan 11 0650</td><td>LHR</td><td></td><td></td><td>30min</td></tr>
<tr><td>D10001_40</td><td>28 Jan 11 2305</td><td>JFK</td><td>29 Jan 11 0620</td><td>LHR</td><td>4hr 56min</td><td>57min</td><td>1hr 23min</td></tr>
<tr><td>D10001_40</td><td>29 Jan 11 0620</td><td>LHR</td><td>29 Jan 11 0650</td><td>LHR</td><td></td><td></td><td>30min</td></tr>
<tr><td>D10002_42</td><td>14 Jan 11 2305</td><td>JFK</td><td>15 Jan 11 0620</td><td>LHR</td><td>5hr 7min</td><td>1hr 17min</td><td>51min</td></tr>
<tr><td>D10002_42</td><td>15 Jan 11 0620</td><td>LHR</td><td>15 Jan 11 0650</td><td>LHR</td><td></td><td></td><td>30min</td></tr>
</table></td></tr>
<tr><td>Reviewing & comparing fatigue exposure business wide</td><td>Comparative analysis of different groups / types / bases / depots can also be considered using FAID Business Wide versions (including Time Zone version).

The Business Wide version of FAID Technology allows users to review outputs grouped by location / depots / base, and/or job type / role, thereby making it easier to compare relative hours of work fatigue exposure across an operation or for the whole organisation.

The map view can be used to quickly identify locations with highest hours of work fatigue exposure for further investigation and drill down.


(Generic map and data example)

</td></tr>
</table>

Type of Analysis	Description
	The below table shows FAID Key Risk Indicators to support monitoring, evaluation, and analysis. Locations with higher hours of work fatigue exposure can be reviewed as a priority for risk improvement action consideration.

Location	Compliance to FTL (%)	Total Hours > FTL	Total Hours Worked	Number of Individuals	Apparent FTL
Location 3	93.7	2,938	46,354	227	106
Location 5	93.8	842	13,638	70	108
Location 2	94.5	268	4,879	27	105
Location 21	94.5	1,461	26,694	124	104
Location 22	94.6	2,083	38,838	174	104
Location 11	95.1	1,407	28,475	126	101
Location 24	95.7	1,729	39,761	179	100
Location 12	96.7	377	11,500	51	96
Location 8	97.4	385	14,605	70	93
Location 18	97.7	278	12,160	61	92
Location 23	97.8	419	19,274	94	91
Location 17	97.9	400	19,265	90	91

Trends can be reviewed over the year to ascertain time periods that are higher risk and may require further risk improvement action.

NETWORK TOTAL

	KPI	Jan 13	Feb 13	Mar 13	Apr 13	May 13	Jun 13	Jul 13	Aug 13	Sep 13	Oct 13	Nov 13	Dec 13
1	Compliance Rate %	99.2	99.0	99.3	99.3	99.7	99.7	99.8	98.3	96.0	95.9	96.6	98.1
2	Individuals	1,508.0	1,500.0	1,458.0	1,358.0	1,299.0	811.0	1,364.0	1,511.0	1,576.0	1,599.0	1,585.0	1,578.0
3	Hours Worked	281,534.5	244,112.9	230,480.6	193,488.2	154,312.6	63,331.3	94,260.9	264,218.3	329,482.9	350,187.3	329,410.6	317,821.3
4	Hours Worked PFCRed	2,239.1	2,553.9	1,584.3	1,387.5	526.9	184.4	194.4	4,610.3	13,284.5	14,477.6	11,043.8	6,056.0
5	Hours Worked PFCYellow	4,667.6	4,204.1	2,924.0	2,302.0	1,172.8	365.1	400.9	5,683.2	12,922.9	14,273.2	12,242.1	8,485.7
6	Hours Worked PFCGreen	274,627.4	237,353.9	225,972.3	189,796.1	152,612.8	62,781.8	93,665.6	253,924.5	303,274.9	321,433.9	306,123.5	303,278.6
7	Hours Worked Per Indv. Per Week	42.2	40.7	35.7	33.2	26.8	18.2	15.6	39.5	48.8	49.5	48.5	45.5
8	Apparent FTL	83.0	84.0	80.0	80.0	74.0	73.0	70.0	89.0	99.0	100.0	97.0	90.0
9	Individuals <90% Compliant	3.0	6.0	3.0	4.0	4.0	8.0	1.0	1.0	84.0	75.0	48.0	12.0
10	Individuals Exceeding FTL	676.0	630.0	483.0	403.0	233.0	56.0	97.0	987.0	1,377.0	1,415.0	1,339.0	1,085.0
11	Peak FAID Score	143.4	132.8	127.5	132.8	129.1	117.1	128.1	128.7	142.5	140.0	139.8	136.4
12	FTL Used	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0

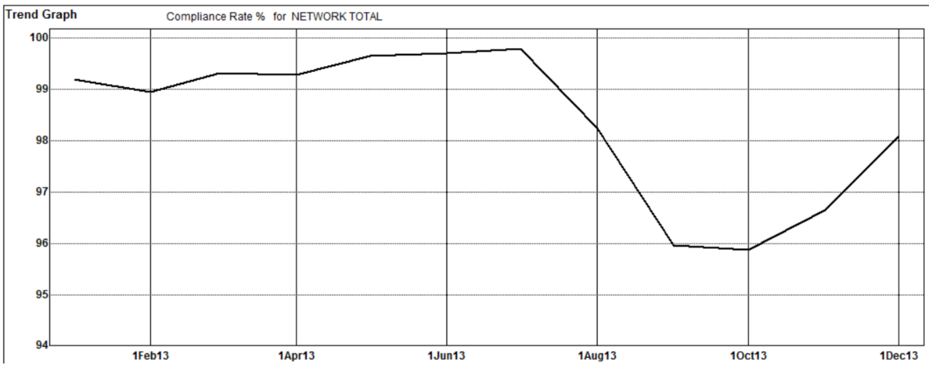
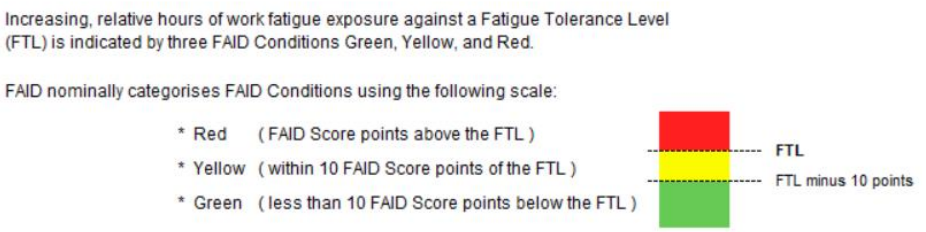


Figure 12 – Proactive Analysis

Predictive Analysis

Type of Analysis	Description
Predictive Analysis: Using FAID to plan and manage hours of work fatigue exposure to within risk levels tolerated by the organisation, including the planning and allocation of duty changes, shift swaps, and ad hoc duties.	
Planning work hours within agreed risk tolerance levels	Once FAID Score benchmarks (Fatigue Tolerance Level & Target Compliance %) are chosen as an outcome of a Fatigue Hazard Analysis risk assessment process for a particular job type, then any future hours of work scenarios can be compared to these benchmarks. Comparisons can be made between different work duty options, pairings, etc. Planning work hours within chosen FAID Score benchmarks enables the management of hours of work fatigue exposure to within tolerable risk levels. FAID Score benchmarks can be set to provide an hours of work fatigue exposure buffer for unplanned events on day of operations. FAID Roster Tool versions of FAID Technology (including Time Zone version) allows users to review the FAID Score impact of different work schedules / duty periods as the work schedule is being built. The below figure shows the work schedule building screen from Sunday to Wednesday within a two week period. The FAID Score impact is shown next to the planned shift / duty in the coloured boxes.



Depot	Service Number	Name	Su 24Mar	Mo 25Mar	Tu 26Mar	We 27Mar	Th 28Mar	Fr 29Mar	Sa 30Mar	Su 31Mar	Mo 01Apr	Tu 02Apr	We 03Apr
Depot A	362	Person AA1											
Depot A	453	Person AA10								Day 12 hr 14	Day 12 hr 27	Night 12 hr 77	Day 080... 67
Depot A	686	Person AA11		Day 12 hr 14	Day 12 hr 27	Night 12 hr 77	Day 080... 67						
Depot A	675	Person AA12	Day 080... 67					Day 12 hr 21	Day 12 hr 35	Night 12 hr 77	Day 080... 67		
Depot A	687	Person AA13								Day 12 hr 14	Day 12 hr 27	Night 12 hr 77	Day 080... 67

Each duty period shown above, to the left of the FAID Score box, can represent a single shift or be broken up into a series of activities for a trip / pairing. For example, a work period could be made up of the following duty period activities (FL = flight duty).

UTC Start	Origin	UTC End	Destn	Activity Code
27 Dec 10 0940	SCL	27 Dec 10 1105	SCL	Brief
27 Dec 10 1105	SCL	27 Dec 10 1455	GRU	FL
27 Dec 10 1545	GRU	27 Dec 10 1650	GIG	FL
27 Dec 10 1650	GIG	27 Dec 10 1731	GIG	Debrief
28 Dec 10 1610	GIG	28 Dec 10 1735	GIG	Brief
28 Dec 10 1735	GIG	28 Dec 10 1850	GRU	FL
28 Dec 10 1940	GRU	28 Dec 10 2355	SCL	FL
28 Dec 10 2355	SCL	29 Dec 10 0036	SCL	Debrief

All the outputs / reports mentioned above under Reactive & Proactive Analysis can also be used to review and evaluate planned hours / duties.

Figure 13 – Predictive Analysis

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