



# Developing the 'Fatigue Impairment Prediction Suite'

*An R Package for Implementing Bio-Mathematical Models*

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*Research Supported by funding from DST Research Agreement [myIP: 6963]*

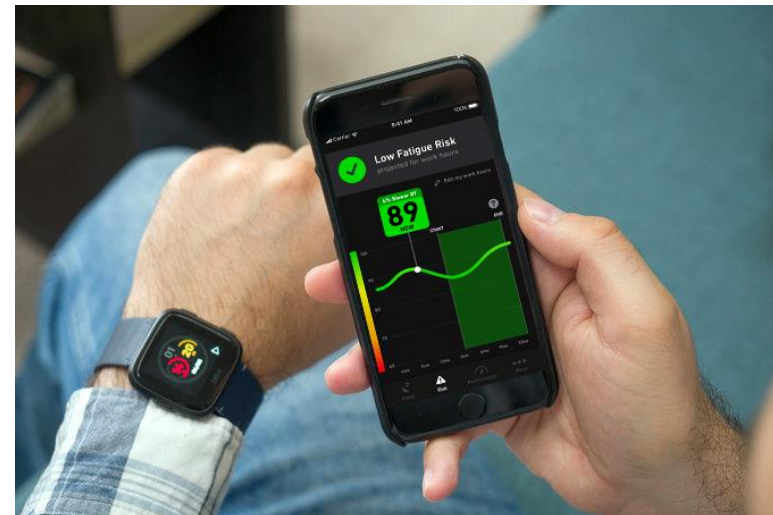
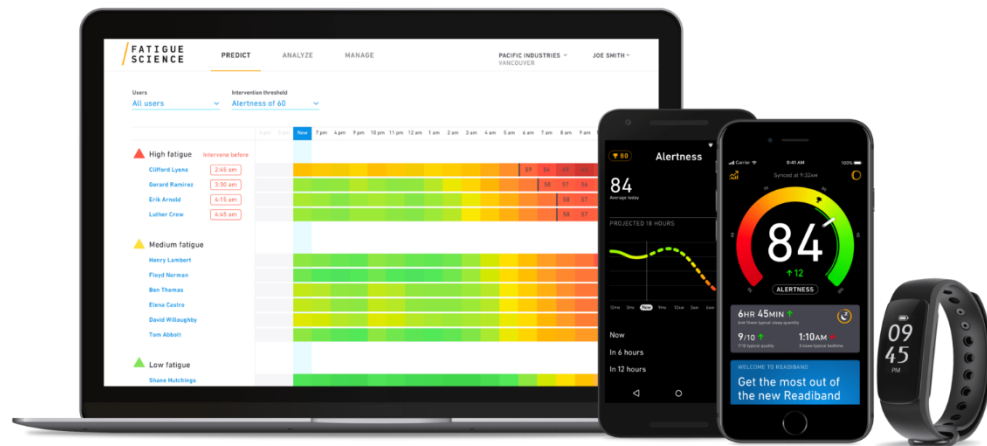
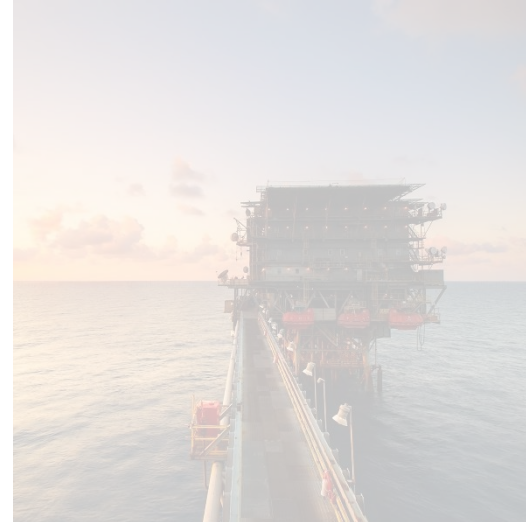
# Outline

1. Brief overview/refresher on fatigue research
2. Introduction to biomathematical model mechanics
3. *Fatigue Impairment Prediction Suite* (FIPS)

# Endurance and Fatigue

- Fatigue is a crucial factor underlying endurance
- A physiological state of reduced mental or physical performance capability
- **Fatigue** arises from multiple often interacting factors
  - Endogenous biological processes – circadian rhythm.
  - Sleep deprivation (acute and chronic)
  - Task factors and motivation (Hockey & Earle, 2006)
- Significant research has associated fatigue with
  - **Neurobehavioral deficits**, posing risks to operational safety and effectiveness.
  - **Decision-making capabilities** (Killgore, Balkin, & Wesensten, 2006)
  - **Increased risk of human error**, including in military settings (Miller, Matsangas, & Shattuck, 2008)
- *Terminology: Fatigue; Sleepiness; Fatigue-related performance; Alertness*

# Fatigue Risk Management Systems



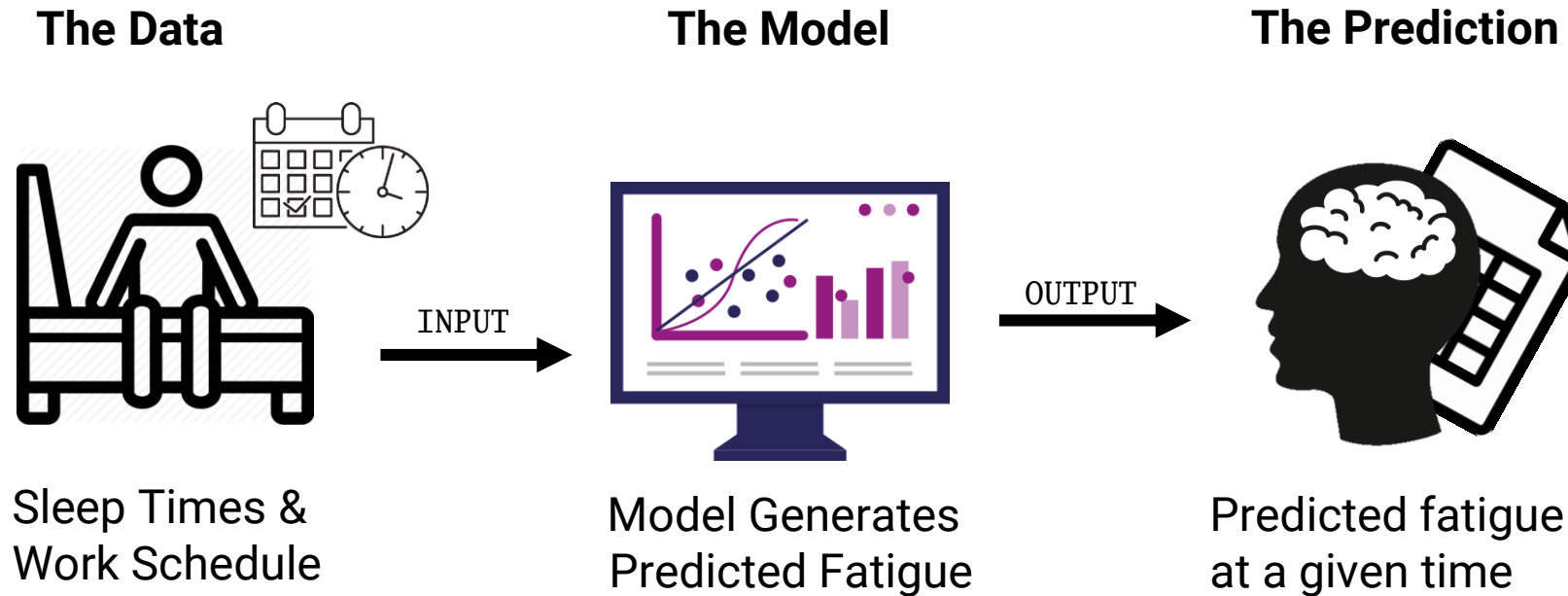
A photograph of a vast ocean with a white rectangular box overlaid in the center containing the text 'Biomathematical Models'. The ocean is dark blue with white-capped waves breaking in the foreground. The sky is a pale, hazy blue. The text is in a clean, white, sans-serif font.

# Biomathematical Models

# What are BMMs?

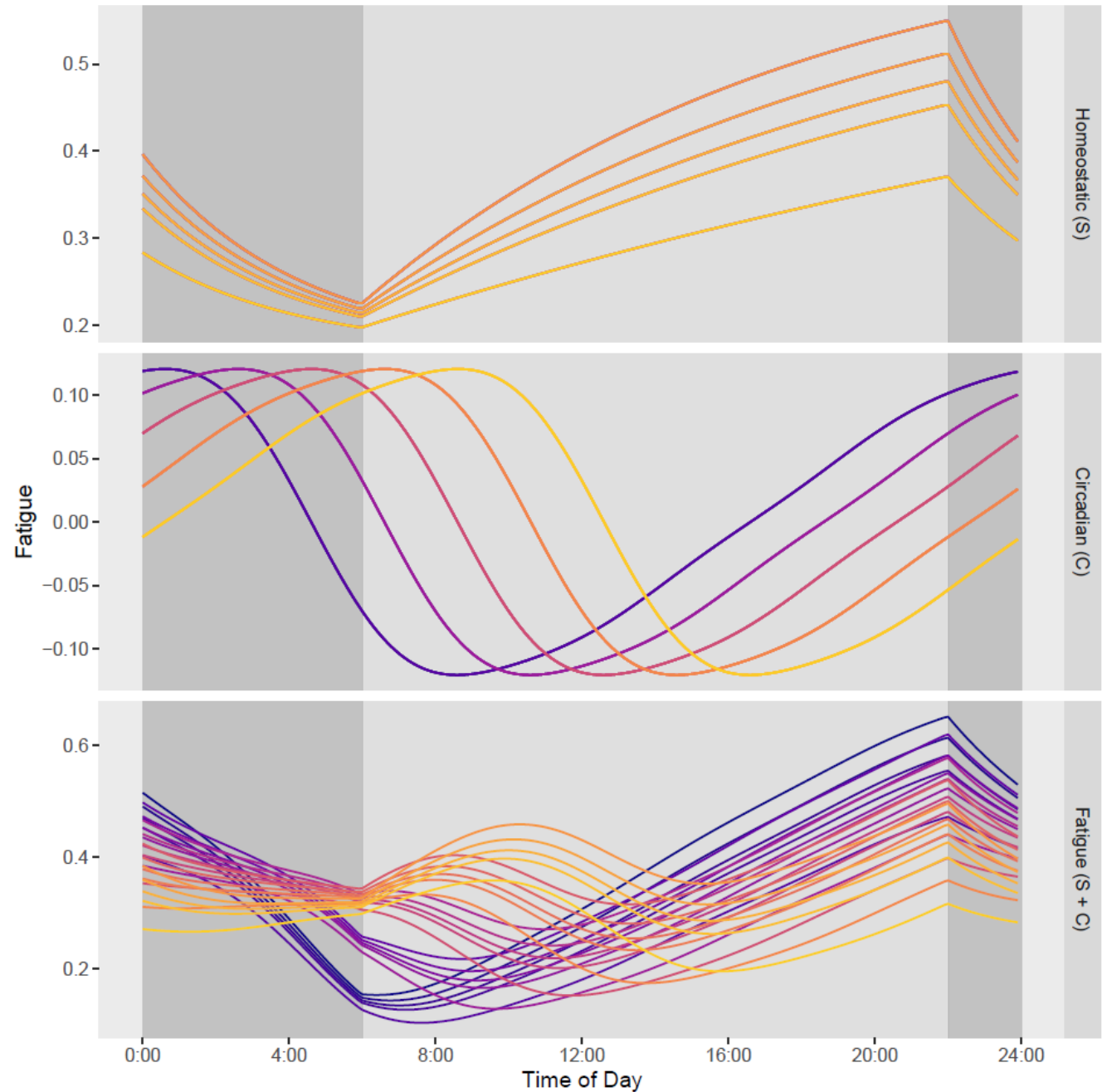
- Biomathematical Models of Fatigue
- Dynamic models for predicting “fatigue-related impairments”
- Take in sleep schedule, output predicted fatigue [or equivalent].
  
- Several peer reviewed and publicly available models:
  - Two & Three Process Models of Alertness (Borbély, 1982; Ingre et al., 2014)
  - Unified Model (Rajdev, Ramakrishnan at colleagues., 2013, 2015, 2016)
- Many commercialised ‘black-box’ proprietary tools in circulation:
  - SAFTE-based model (note some model formulations published)
  - *FAID* model
  - *CAS, BAM*

# Basic Mechanics of Fatigue BMMs



# Two Process Model: Basic Mechanics

- Majority of BMMs derived from Borbély's (1982) - '*Two-Process Model*'
  - Two core functions/processes
  - $S + C = \text{Alertness/Fatigue}$
- Parameters normally fixed, but variation shown in plots.





# Limitations of BMMs

- Fixed model parameters derived from populations/averages
- Average model may not be representative of any individual within the sample (Ly et al., 2017)
- Conventional BMMs developed using short-term sleep deprivation studies
- Parameters rarely estimated in practice

# Closed Source!

## Most proprietary tools are closed source

*“Why **exactly** did a model make a particular prediction?”*

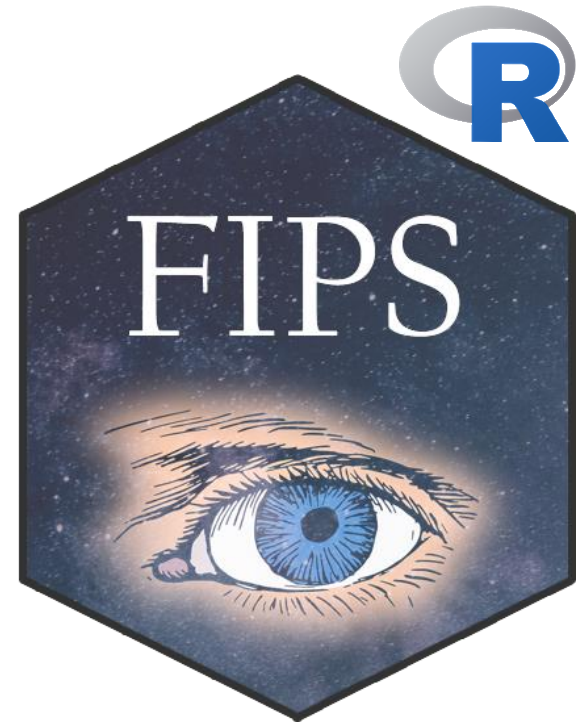
*“How can I conduct independent model validation?”*

*“What normalisation was conducted on predicted values?”*



# Introduction to FIPS Package

- *Fatigue Impairment Prediction Suite* (FIPS)
- Implemented in R.
- Aims to provide a comprehensive set of functions for estimating and applying bio-mathematical models (BMMs) of fatigue.
- Open Source (likely GPL v3.0)



**Planned 0.1.0 Release: Q1 2020**  
**Planned 0.2.0 Release: Q2 2020**

# FIPS Feature Comparison

- FIPS is a **framework** for BMM
  - Implements *multiple* models
  - Supports parameter estimation
  - Allows simulation and prediction
  - Extendable and introspectable (to be built upon)
- Alternatives (e.g., FAID, SAFTE):
  - Provide modelling tool
  - Implements single model
  - Prediction only

# Simulation Interface: Run Simulation

la	2.4000
ha	14.3000
d	-0.0353
g	-0.3814
bl	12.2000
Cm	0.0000
Ca	2.5000
p	16.8000
Um	-0.5000
Ua	0.5000
Wc	-5.7200
Wd	-1.5100
S0	7.9600

+

	sleep.start	sleep.end	sleep.id
1	2018-05-21 01:00:00	2018-05-21 08:00:00	1
2	2018-05-21 18:00:00	2018-05-22 01:00:00	2
3	2018-05-22 11:00:00	2018-05-22 18:00:00	3
4	2018-05-23 04:00:00	2018-05-23 11:00:00	4
5	2018-05-23 21:00:00	2018-05-24 04:00:00	5
6	2018-05-24 14:00:00	2018-05-24 21:00:00	6
7	2018-05-25 07:00:00	2018-05-25 14:00:00	7
8	2018-05-26 00:00:00	2018-05-26 07:00:00	8

Sleep history information

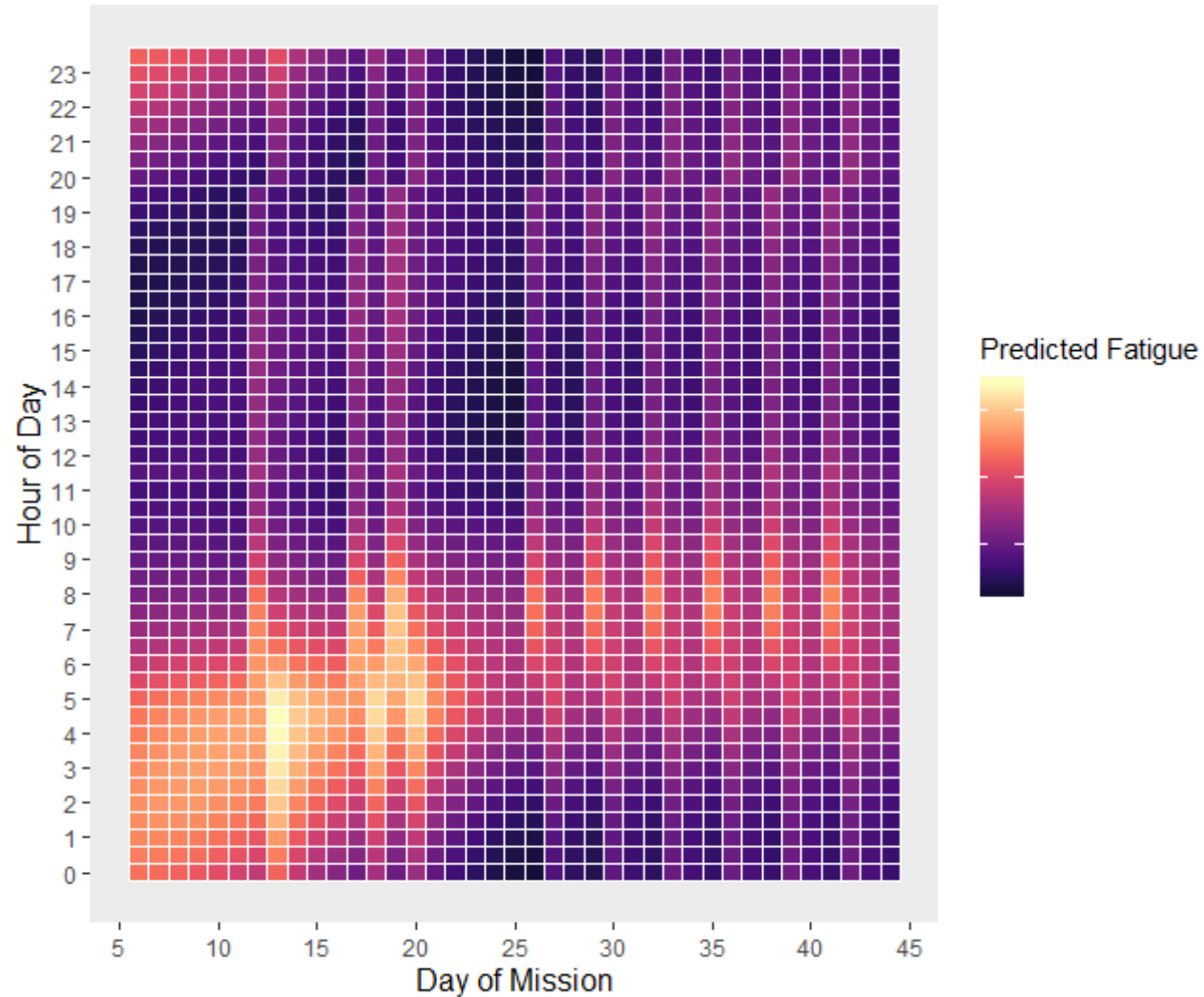
Parameter vector

# Simulation Interface: Run Simulation

	datetime	s	l	c	w	u	alertness	KSS
1	2018-05-20 01:00:00	7.960	NA	-1.36160	-5.720e+00	-9.568e-01	5.642	7.215
2	2018-05-20 01:05:00	7.944	NA	-1.40701	-5.044e+00	-9.652e-01	5.571	7.257
3	2018-05-20 01:10:00	7.927	NA	-1.45176	-4.447e+00	-9.728e-01	5.503	7.298
4	2018-05-20 01:15:00	7.911	NA	-1.49581	-3.921e+00	-9.794e-01	5.436	7.338
5	2018-05-20 01:20:00	7.895	NA	-1.53915	-3.458e+00	-9.851e-01	5.371	7.378
6	2018-05-20 01:25:00	7.879	NA	-1.58176	-3.049e+00	-9.900e-01	5.307	7.416
7	2018-05-20 01:30:00	7.863	NA	-1.62362	-2.688e+00	-9.938e-01	5.245	7.453

# Forecasting Fatigue with FIPS

- Built-in visualisation methods
- Summary statistics



# Estimating the Parameters

- All simulations here used fixed parameters
- FIPS can perform parameter estimation
  - Additionally requires fatigue measurements (i.e., PVT)
- **Enables individualised and tailored predictions**

	<b>LOOIC</b>	<b>WAIC</b>
2PM Regression	1576.30 (25.73)	1576.29 (25.73)
2PM Group Estimates	1566.34 (25.54)	1566.30 (25.53)
2PM Individual Estimates	<b>1490.78 (29.64)</b>	<b>1480.32 (30.11)</b>



la	2.4000
ha	14.3000
d	-0.0353
g	-0.3814
bl	12.2000
Cm	0.0000
Ca	2.5000
p	16.8000
Um	-0.5000
Ua	0.5000
Wc	-5.7200
Wd	-1.5100
S0	7.9600



# Performance Evaluation

- Data from 43 naval crew over 7-14 day periods (active mission)
  - Full sleep history information (objective)
  - Sleepiness 1-9 (KSS)
  - 10-40 observations per person.
- FIPS is not a model itself, it implements others.
- Two-process model in FIPS compared to SAFTE-FAST

**Human  
Neurobiology**

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## A Two Process Model of Sleep Regulation

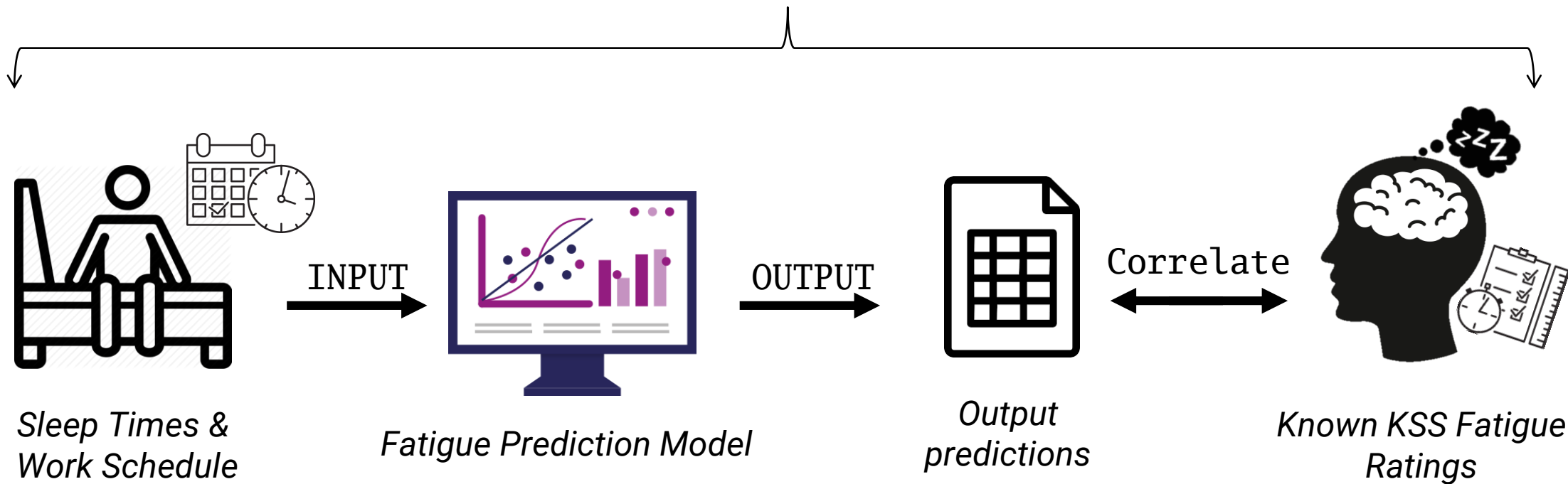
A.A. Borbély

Institute of Pharmacology, University of Zürich, Zürich, Switzerland



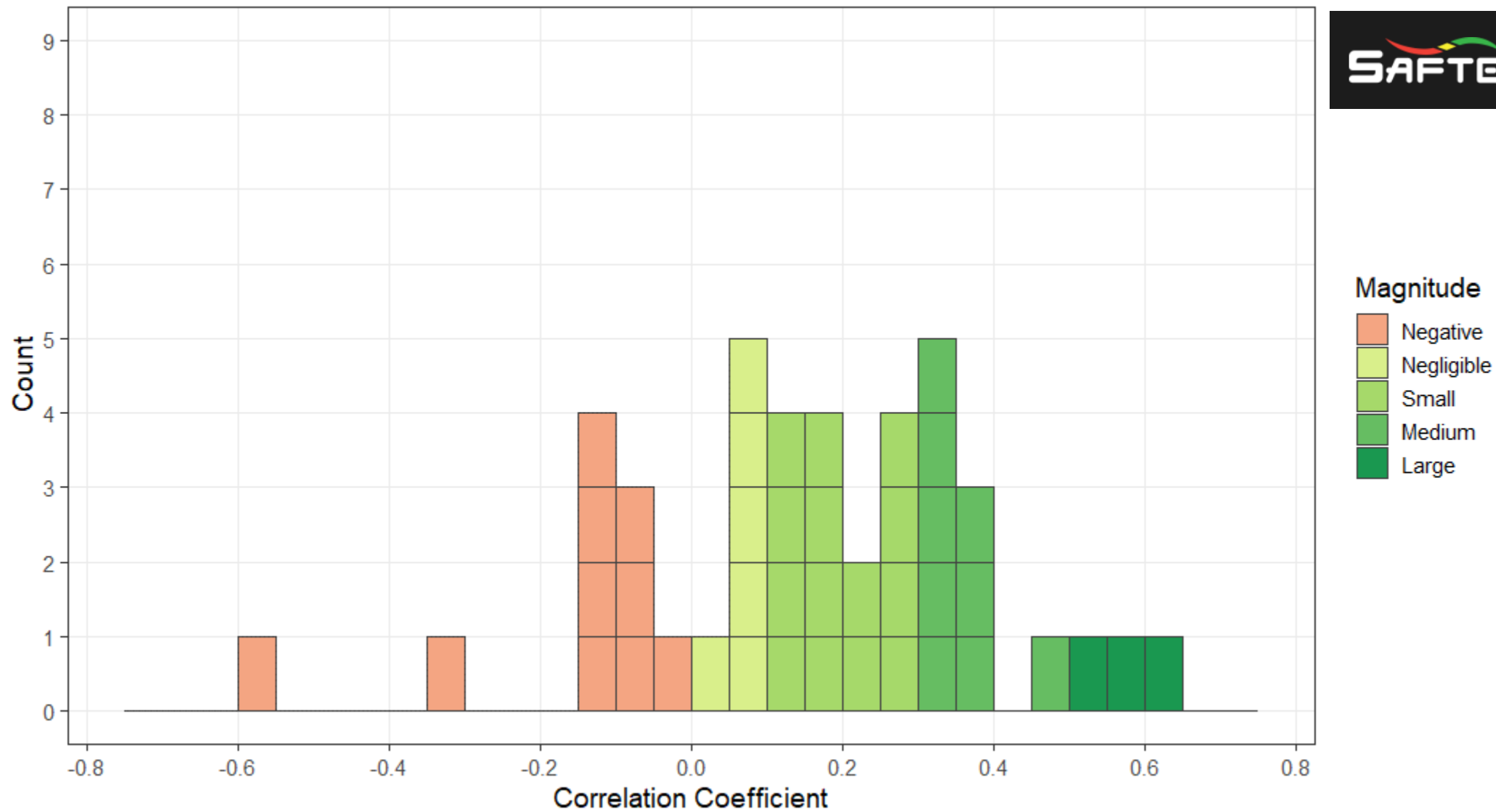
# Step 1: Generating Model Predictions

For each participant & each model



1 correlation per person and model

# SAFTE-FAST Performance

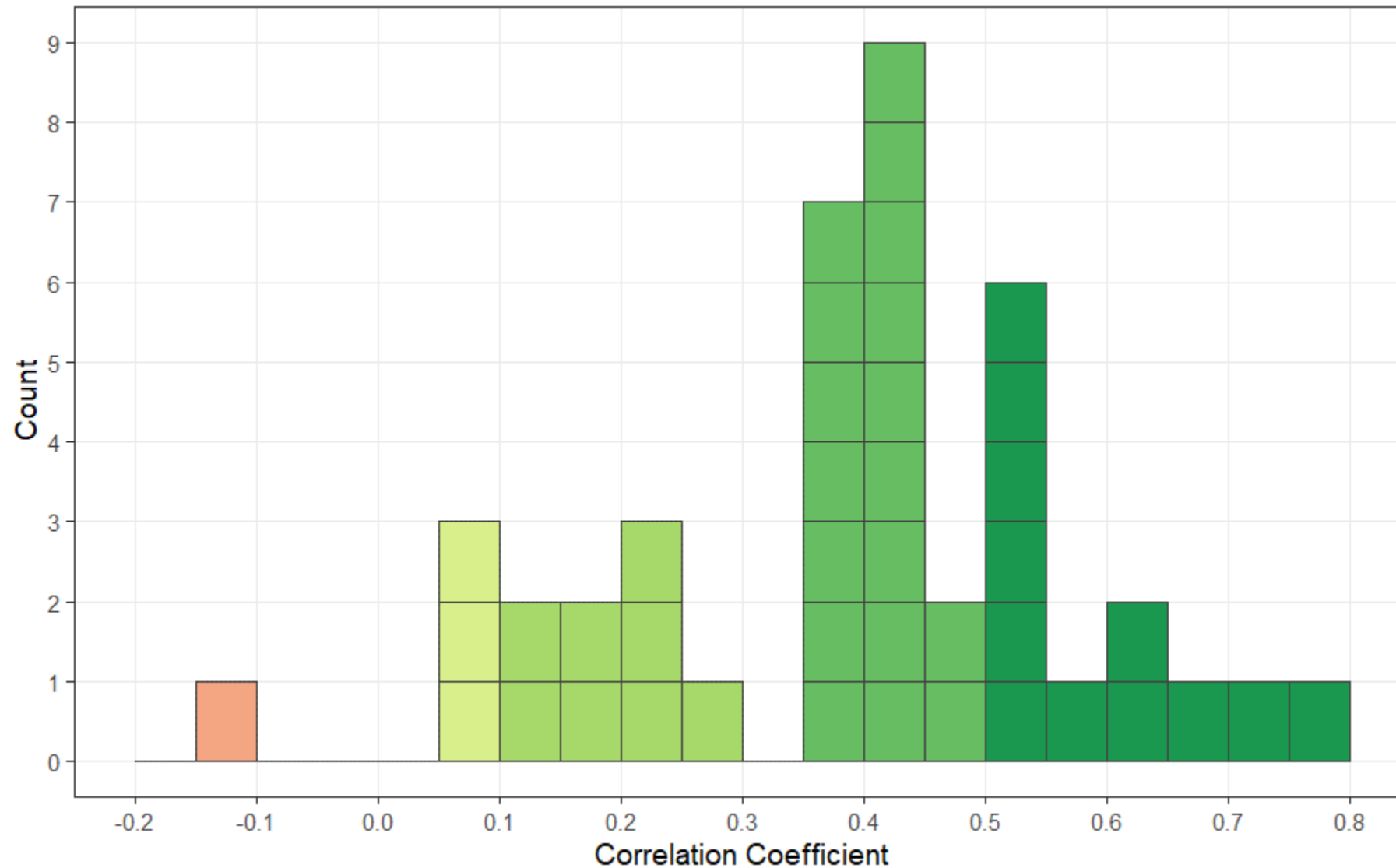


# Two Process Model Performance



**Human  
Neurobiology**

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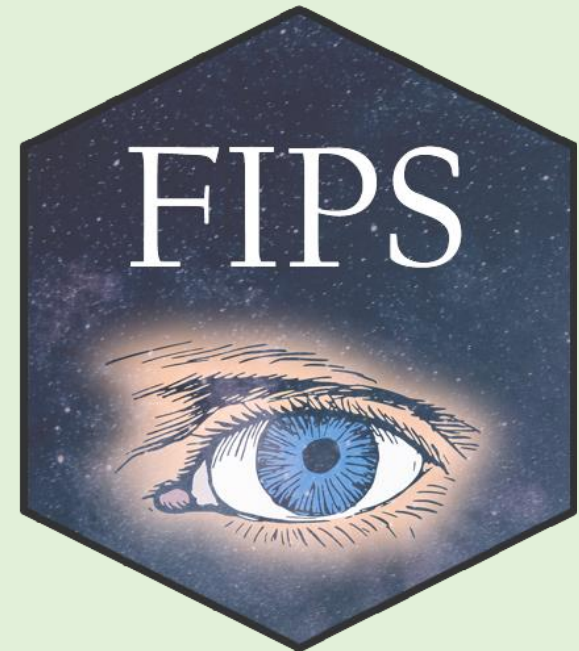


# Immediate Conclusions

- Proprietary models are seriously limited by their closed nature
- BMMs must be **introspectable** and **transparent** if we seriously want to **depend** on their predictions in novel contexts
- Parameter estimation not just scientific
- Ultimate approach involves tailoring parameters
  - ‘Model training’ prior to prediction (requiring measurement).
  - Domain / Watch / Job Role / Individual

# FIPS Moving Forward

- **Attract industry, researcher, and practitioner interest.**
- Refine Bayesian parameter estimation procedures
- Improve GUI version of application (stretch goal)
- Increase validation datasets with industry samples



# Thankyou – Question Time

## Summary

- Biomathematical models enable fatigue forecasting
- Widely implemented, but limited.
- FIPS is a framework for developing these models.

## Contact Information

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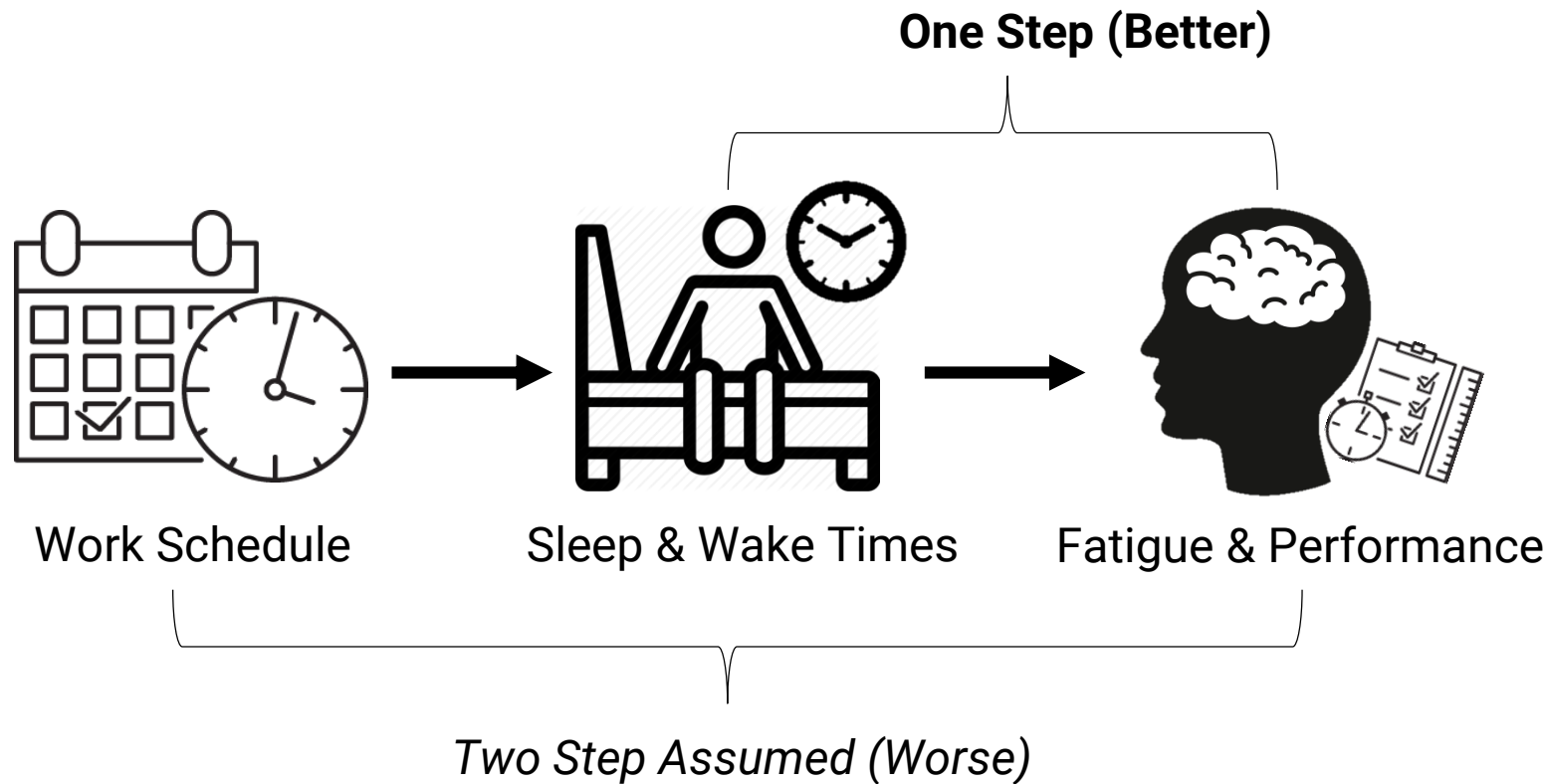
 @humanfactorsio



Curtin University

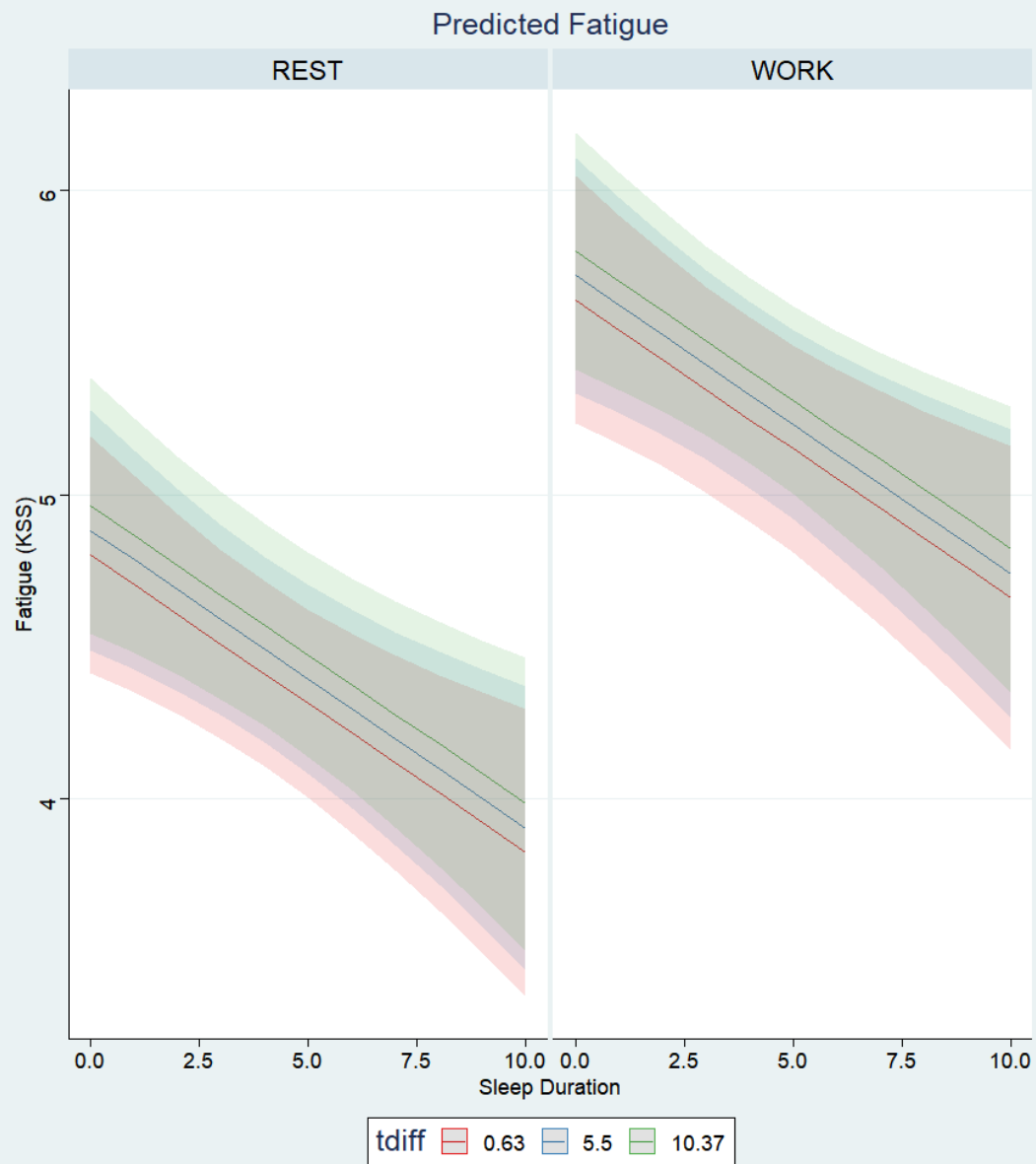
FUTURE OF WORK INSTITUTE

# Appendix: Types of Modelling Tools





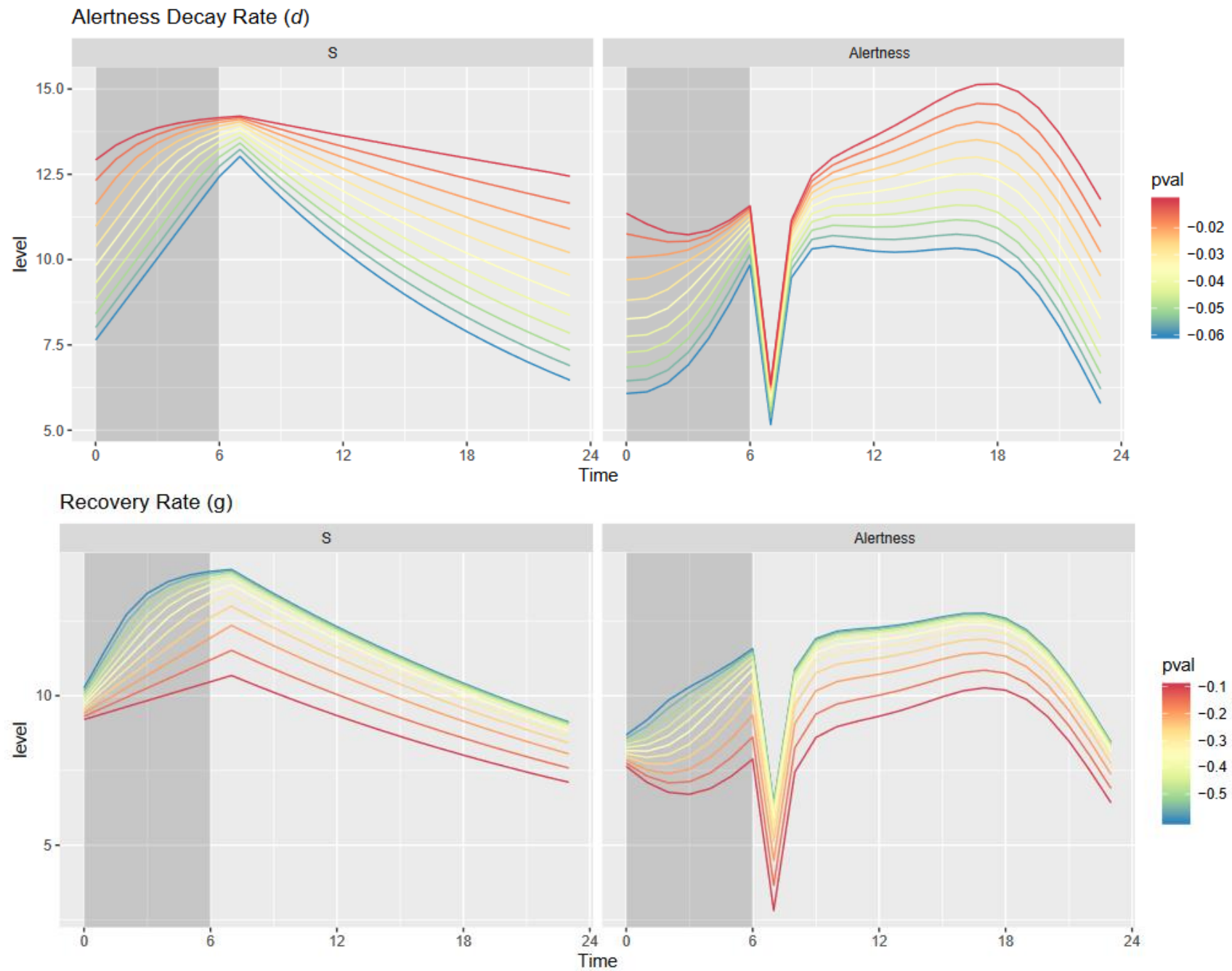
# Appendix: Manifest Fatigue Analyses



<i>Predictors</i>	<b>Sleepiness (Fatigue)</b>		
	<i>Estimates</i>	<i>CI</i>	<i>p</i>
(Intercept)	4.81	4.47 – 5.14	<b>&lt;0.001</b>
Post-Work	0.80	0.62 – 0.98	<b>&lt;0.001</b>
Sleep Duration (L1)	-0.11	-0.18 – -0.03	<b>0.008</b>
Time Awake (L1)	0.03	0.01 – 0.04	<b>0.011</b>
Days into Mission	-0.07	-0.10 – -0.05	<b>&lt;0.001</b>
<b>Random Effects</b>			
$\sigma^2$	2.17		
$\tau_{00}$ Subjects	0.82		
ICC	0.27		
N Subjects	42		
Observations	1430		
Marginal R <sup>2</sup> / Conditional R <sup>2</sup>	8.6% / 33.7%		

Note the inversed scale!  
(Alertness)

## S Governing Parameters



# Appendix: GUI Forecasting of Fatigue with FIPS

## Data Upload Interface

The screenshot shows the 'Data Upload' section of the 'Fatigue Simulation' interface. It features a dark sidebar with navigation options: Introduction, Data Upload (selected), Model Setup, and Model Results. The main content area is titled 'Fatigue Simulation' and contains the following fields:

- Simulation Start Date & Time:** 2018-05-01 at 08:00 pm
- Simulation End Date & Time:** 2018-05-01 at 08:00 pm
- File:** A 'Browse...' button and a status 'No file selected'.
- Delimiter:** A dropdown menu set to 'Comma'.
- Decimal mark:** A dropdown menu set to 'Point'.
- Timezone to parse:** A dropdown menu.
- Timezone to display:** A dropdown menu.
- Data Pre-Processing:** A 'Transform Data' button and an empty input field.

## Working prototype of model setting interface

The screenshot shows the 'Model Setup' section of the 'Fatigue Simulation' interface. It features a dark sidebar with navigation options: Introduction, Data Upload, Model Setup (selected), and Model Results. The main content area is titled 'Fatigue Simulation' and contains a 'Widgets' section with the following parameters:

- Fatigue Startpoint:** Initial Value of S: 0
- Upper Asymptote:** Maximum level of sleepiness: 24.12
- Lower Asymptote:** Minimum level of sleepiness: 0
- Tau Sleep:** controls rate of decay in S during sleep: 1
- Tau Wake:** controls rate of rise in S during wake: 18.2
- Tau Lambda:** rate of change in lower asymptote: 4.06
- Phi:** phase at beginning of the simulation (I think this should be 0 if t = tod): 2.02
- Kappa:** influence of circadian process - represents A in this model: 4.13
- Sleep Inertia Initial:** extent of alertness reduction at time of waking (typically = -5.72, but sign is reversed for 2PM): 5.72
- Sleep Inertia Recovery:** exponential recovery of alertness (typically = -1.51): -1.51

# Appendix: FIPS Comparison Chart

	<b>FIPS</b>	<b>Commercial Tools</b>	<b>Published Models</b>
Expertise Required	✓ Any	✓ Minimal Expertise	✗ Experts only
Fatigue Forecasting	✓	✓	✓
Introspectable	✓	✗	✓
Modifiable/Tailorable	✓	✗	✓
Multiple Models	✓	✗	—
Parameter estimation	✓	✗	—
Cost	Free	Expensive	Free
Sleep Prediction	✗	✓	—