

## Evaluating Bio-Mathematical Models of Fatigue in Workplace

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**Abstract**-In recent years, theoretical models of daily sleep and relaxation have been proposed as means of fatigue prediction and efficient performance deduction. These models are ordinarily formulated using the input variables of sleep, wakeful and/or working hours. Moreover, the anticipated variables act as the output of these models. The aim of this article is to provide details on fatigue and its consequent hazards for employers, organizations and manufacturing firms. This article is an attempt to recommend an efficient pattern of sleep and work in order for a preferable consideration of fatigue hazards in addition to the prevention of incidents for the purpose of effective productivity. To reach this outcome, firstly the influential variables on fatigue in the workplace are briefly reviewed. Furthermore in the available research literature, the present fatigue models are discussed. Ultimately, the Bio-Mathematical models of fatigue in the workplace are explored and examined. The expected outcome of this paper is to inform the organizational executives in order to set more effective policies. This will result in fully handling the hazards arising from the worker's fatigue in the work and production environment.

**Keywords:** Fatigue, Sleep-wake cycle, Circadian rhythms, Shift work, Occupational health and safety

## 1.Introduction

The fluctuations in the global economics and working life cause the speedy process of business and hence its tangible presence visible in the society. In many developed countries the work structure has grown to be faster and more severe [40].The elevated time pressure requires more and more efficient employees. In many departments , the flexibility of the personnel is expected. High levels of effectiveness need to be gained regardless of the extended working hours and shortage breaks or rests. This, in itself, results to more irregularity from the beginning to the ending of work shifts[20].Fatigue, mild rhythm of the work volume and sufficient sleep are unanimously considered as significant elements for increased levels of productive work among the employees[3],[26].In reality, fatigue is one of the key characteristics of the modern lifestyle. There are various consequences of fatigue. The most significant of these are the acute and chronic types of fatigue that ultimately results in the exhaustion and discontent of the employees[27].

These sorts of fatigue are regularly caused by muscles[21],mental fatigue (consequent of mental or intellectual labor)[5],mental fatigue due to work overload or the repetitive use of the same neural system subdivision[22],chronic fatigue resulting from viral agents, permanent diseases and allergies of the employees[7],[16],[22].Even though different types of fatigue are discussed in this article, the focus point is to utilize the duration of sleep and the entire neural process of drowsiness due to sleep adjustment and daily rhythm. For instance, we can name driving drowsily[14],[15].According to recent studies by the scholars, the consequences of fatigue on the employees illustrate an imbalance between the intensity/duration of work and the rest duration [47],[25],[31],[42].This imbalance is often related to long work and consequently the inability to sustain a preferable level of performance[15].

Fatigue due to lack of sleep is among the most known elements. This element is associated with long periods of repetitive work, job stress, instability in the employee's performance, reduction of security and increased disease risk[26].Fatigue, resulting from lack of sleep is one of the most frequent incidents among the drivers working at the workshops [17],[43].Long periods of work also help to raise the risk of incidents[6].The long term effects of employee fatigue, resulting from long periods of work and mandatory overtime work, leads to wards increased mental distress, physical disorders and cardiovascular diseases [12],[24],[45].In earlier studies, the association between the reduction of sleep time, obesity, diabetes and also skeletal/muscular injuries has been fully proved[46].In shift workers, with respect to many changes in working hours their sleeping habits are disturbed. This industry. Contributed to the fact that shift work is known as the most widespread reasons of employee fatigue, the attempt for reconsideration in the model so that we are able to assess and estimate fatigue according to working hours is fully evident. Utilizing the BMMF model we are capable to predict levels of sleep in regard to type of work, Work adjustment must be in a way that the employee's awareness is fully maintained and also lower

in itself results in the employee's substandard performance and also the effectiveness of the worker [2],[12].Studies have illustrated that fatigue and sleep time reduction can have direct influence on the functioning of the brain. Hence, the tasks that require oral skills ,mental skills, response control, innovation, flexible thinking and emotional control are highly distorted [28],[27],[35],[44].

## 2.Bio-mathematical Models of Fatigue (BMMF)

The bio-mathematical model of fatigue attempts to predict the impacts of various work patterns on job performance. Moreover, it also considers the scientific input with regard to the relationship between working hours, sleep and employee performance. Recently it has utilized a quantitative structure regarding expression pattern at workplace in order to adjust work periods, daily scheduling, duration, assessment of sleep/wakefulness and also to comprehend the sleep behavior. On these basis, it seems that at least theoretically, we can find quantitative models that are able to predict the levels of fatigue according to the employee working patterns. Furthermore, the comparison of fatigue regarding the movement pattern and the models utilized to better inform the executives. This aids the executives for more efficient decision making in the organizations. Additionally, it causes the full management of risks concerning employee fatigue in the workplace, and at the time of manufacturing.

Many manufacturing companies are interested to utilize the complex solutions for the automated control of the employees, improvement of employee's working conditions, raise company's productivity and community health. As a result, the revision and adoption of BMMF model is nearly inevitable. However, the models presented so far are solely mechanized for the simplification of industrialized psychology. Therefore, the decision making on the alterations is purely scientific. In the end, a political and cultural decision is achieved that illustrates the ideology and values of a system and its founders. In addition to official recognition of the benefits resulting from BMMF, if we make decisions in accordance to this model we achieve our desired goal of production thanks to the simplification of this technology.

## 3.Possible Uses of Bio-mathematical Models

Regarding the negative aspects of fatigue on community health and welfare[34],governments all around the globe are increasingly attempting to make the compulsory terms in order to minimize the undesirable impacts of fatigue [32]as changes in the their public politics. Specifically, there is much enthusiasm about the assessment of risk along fatigue regarding work for the quantitative determination of risk ratio in regard to wide spectrum of work and work adjustment in the

the risk rate. Furthermore, BMMF is able to function harmoniously with a wide spectrum of individual monitoring devices or in the combination with other sensor systems.

General combinations with unique characteristics can improve our sensitivity in detection of increased fatigue or even warnings in the future periods. The suitable proposed model necessarily will be capable to warn

individuals of the potential increase of fatigue and consequent risks. It can easily be elaborated that how the changes in the duration of sleep or the beginning of sleep and following fatigue can help us to deeply comprehend the adjustment system of sleep and risks arising from disturbance of sleep in a day to day life. The sole possession of comprehension of dynamic system of sleep and awareness and its influence on sleep can aid in informing people of the risks arising from fatigue. Also it helps to provide a better planning opportunity and strategic management to decrease the risk. Theoretically, the utilization of fatigues models brings forward the opportunity to merge our understanding of physiology and psychology aspects of fatigue. It is perceptible that in the future in order to refine the model it is required to investigate other complementing indices such as the impact of narcotics (caffeine, alcohol and etc), time devoted to work, stress, lighting of workshop, individual's personal health, employee gender, age and etc.

#### 4.Literature and Review

In 1960,for the first time a model was proposed in order to assess the behavior of work and rest by Pittendrigh[41].By the end of the year 1970, bio-mathematical models were offered to demonstrate the complex disturbance of human sleep and awareness and daily systems for the purpose of better understanding of scheduling and natural and empirical time period [41].At first [8],[33],a model was offered to predict the dynamics of sleep/wakefulness cycles and specifically sleep. Afterwards they were able to predict awareness and nervous performance and in some cases the act of risk management. Meanwhile at Harvard [33]it was proposed that risk rate of fatigue can be predicted using the daily heat rhythm activity/sleep with their interaction using differential equations .According to the theory of Wever in 1979, the influence of temperature on activity is nearly 5 times more influential than rhythms activity temperature. The process of modification by Bobely and others without much development commenced from the two fluctuation models. Neither Borberly in 1982 nor Kronaur and colleagues in 1982 didn't take into

consideration rapid eye movement (NREM)Rapid Eye Movement (REM) as one of the influential elements in the process and a significant element regarding the desire to sleep, wakefulness, nervous performance behaviors.

Independent from the modeling of sleep desire, wakefulness and performance [36],[37]mutual interaction of two sets of neurons utilizing the differential equations was offered as the new variable engaged. In the real world, with the aid of various adjustments and organization we are capable of decision making on risk arising from employee fatigue in the workplace and application of policies in regard to fatigue management. The models of employee fatigue can be generally divided in two main types. The first type of models is which at the time and duration of sleep real individual or group and sleep behaviors are used for the purpose of estimating the level of fatigue and awareness. The second type of models is which with the aid of the work completion time and understanding of time and duration of sleep and required awareness attempt to estimate the level of awareness and fatigue of the employee. In order to achieve the goals of this study, we would like to describe these two types as one stage models(meaning the cases which fatigue is measured directly from the duration of sleep)or the two stage models(meaning the cases which fatigue is directly measured from the duration required to complete a given task).For better comprehension, we have to consider the Figure1.

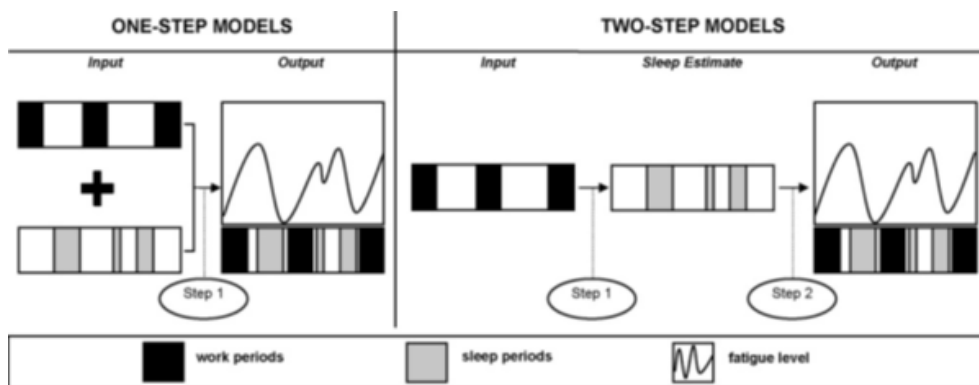


Figure1.Schematic representations of one-step and two-step models of human fatigue and performance. This figure is provided by Dr. Greg Roach and Dr. David Darwent from the Centre for Sleep Research at the University of South Australia.

### 5. A Brief History of Bio-mathematical Modelling

The process model [4], [9], [38], as a matured process of physiology models of sleep and sleep desire and the necessary prediction for the level of awareness. In addition, it has led to the improvement of other models of neural behavior performance. The implementation has been modeled according to inputs of sleep and wakefulness in different phases of daily work. With the use of brain scans during sleep, the model can be improved and work with 3 processes [1], [38]. Hence, the model using the available records and reviews on the employee can estimate the required sleep and predict the optimum wakeful conditions of mental and neural system performance in order to manage the work and prevent the occurrence of inevitable accidents in the workplace.

For instance the fatigue of employees and pilots of airplanes can be reviewed [10], [38]. The procedure of one stage prediction and two stage prediction of fatigue model and the neural systems performance is well illustrated [19]. The mutual neural model is a linear combination of awareness formula, daily rhythm and the required sleep [30], [38]. In the SAFTE model there is a process of increase in the daily rhythm, sleep and awareness that in which sleep and date of wakefulness is directly measured as an input variable [29], [38]. In this model we are able to estimate the timing of change of task and place for the muscular, neural and eye relaxation. Model designed Davson [18] in contrast with other BMMF models discovered mental state before sleep and wakefulness. This means that the workers need be assigned related tasks with regard to their body fitness. This reduces the occurrence of fatigue and incidents. With this methodology the fatigue can be managed in real time on individual levels and regardless of the technology. Fatigue hazards can be measured from a simple set of laws and sleep rate in 24/48 hours before the beginning of work and the duration of sleep and full alertness of the employees.

### 6. Discussion

Few mathematical methods described in the previous section, each to various levels with the use of software and practical programs available to executives and employees so that they can manage fatigue levels, safety assessment and productivity of employee that take part in the various shift works. Many available softwares at the moment are very precise, simple, logical and can aid the executives in prediction of sleep deprivation, full awareness after sleep, increase of neural system's performance in order to use limbs efficiently and reduce the risks of imbalance between mind and body. In figure 2 an example is given which illuminates this matter. In the

figure, fatigue in various units has been measured and the threshold value or the standard scale has been compared to each other. This helps to bring about better comprehension of the fatigue possibility during the employee's task and doing their duties and overall estimation of risk occurrence proportional to the employee fatigue. Practical software of bio-mathematical models that are in the hands of organizations seems to view in a general structure suggesting employee's fatigue in the workplace.

These organizations are usually divided into two groups, the first group is an organization that has proposed in using the fatigue models in order to at least partially suggest with respect to the cultural background [39]. In these organizations one maximum fatigue is pre-determined for each employee and a new pattern with the change of fatigue rate more than the previous level will be opposed to. This means that the repetition of fatigue periods and invariable work and sleep periods are prevented. The second group is an organization that uses models that are made flexible and this means that their approach is modeled in a way that the danger threshold for the employee has been divided into four parts. The green region is the regions of minimum risk. Yellow means the risk levels are high but controllable. The red region means that the risk has enormously increased but still manageable. In the black region the risk is quite evident and it cannot be confided nor does the employee can stand it.

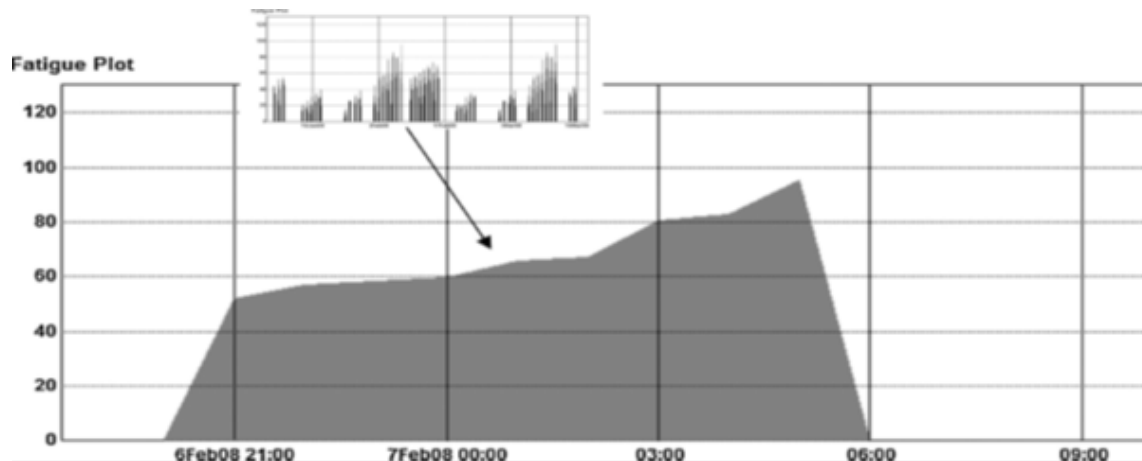


Figure 2. FAID plot representing the time course of predicted 'sleep opportunity' or 'average work-related fatigue' levels across a 4-month time period based on hours of work and rest. Time is displayed across the horizontal axis and the FAID score on the vertical axis. The inset figure shows the entire 4-month period with each 'spike' indicating a single shift period. The larger figure shows the time course of the sleep opportunity/fatigue score across a single shift. In this part of the figure, the 'sleep opportunity' or average work-related fatigue' scores rise from around FAID50 at 21:00 h and increases to a maximum value just below FAID100 at around 05:00 h. Scores are zero at the start and end of the shift since the plot indicated work-related scores and the work-related score will be by definition zero.

### 7. Limitations of bio-mathematical Models of Fatigue

At the moment there are only limited studies being published on the methods of model adjustment in the workplace. Also, the available literature, reliable and valid measures regarding the successful use of risk management models of fatigue in the workplace is not available. Many organizations in order to implement these models without having the knowledge of the impact of fatigue management and rest of employees either with medical document or absence from work will be doubtful and prefer not to utilize the model fully in their organizations. On the whole, the limited bio-mathematical models of work force in the workplace can be divided into five brief parts;

1. Inherent diversity in the input data of different organizations: this means to specify fatigue measurements according to the type of work and the variables involved in the input of the model. Figure 3 shows this diversity in the measurements of fatigue in different categories of work.

2. Sensitivity of present models to primitive parameters in the simulation fatigue model. This means that in various people the sleep and rest duration and levels of awareness are different. The difference occurs in time duration. In the chaos theory, it is evident that conditions

such as the weather, lighting and temperature has influence on the nervous system of employees and the level it is required to restore the employee's full awareness.

3. Mental and social factors in these models and the timing of its application are also influential. This is specifically true for shift workers, that affect the biological causes of sleep and awareness. Figure 3 is an example of this and to further illuminate this. In the figure the data gathered from pilots of an airline in one stage and two stage sleep and full awareness after waking up is assessed. This example shows that the sleep duration and the sleep place are very significant to the level of pilot's awareness. Hence, various levels of sleep with the change of sleep pattern change too. Pilots in long flights have different behaviors from the short flights' pilots. Figure 4 displays that this difference in pattern is caused by personal, mental, social and timing of resting differences.

4. Pure limitation in our ability to predict fatigue on individual levels. This matter arises because of various physical and mental capabilities of people.

5. Enough validation in the correct performance of the model in the analysis of nervous behaviors of employees is not available. There are not enough literature on the topic.

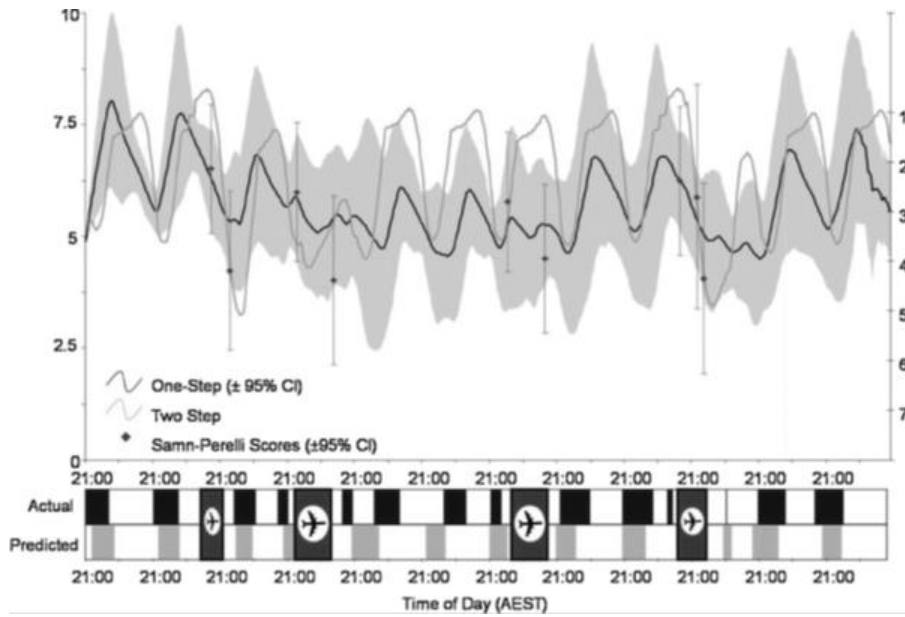


Figure 3. Comparison of one and two-step approaches using data obtained from airline pilots (n = 21) flying from Australia to Bangkok, London and Singapore. The figure (from Kandelaars, 2006) includes a comparison of both the alertness levels obtained using the one-step approach (with 95% CI) with the two-step approach output and self-rated Samn - Perelli fatigue ratings completed pre- and post-duty periods.

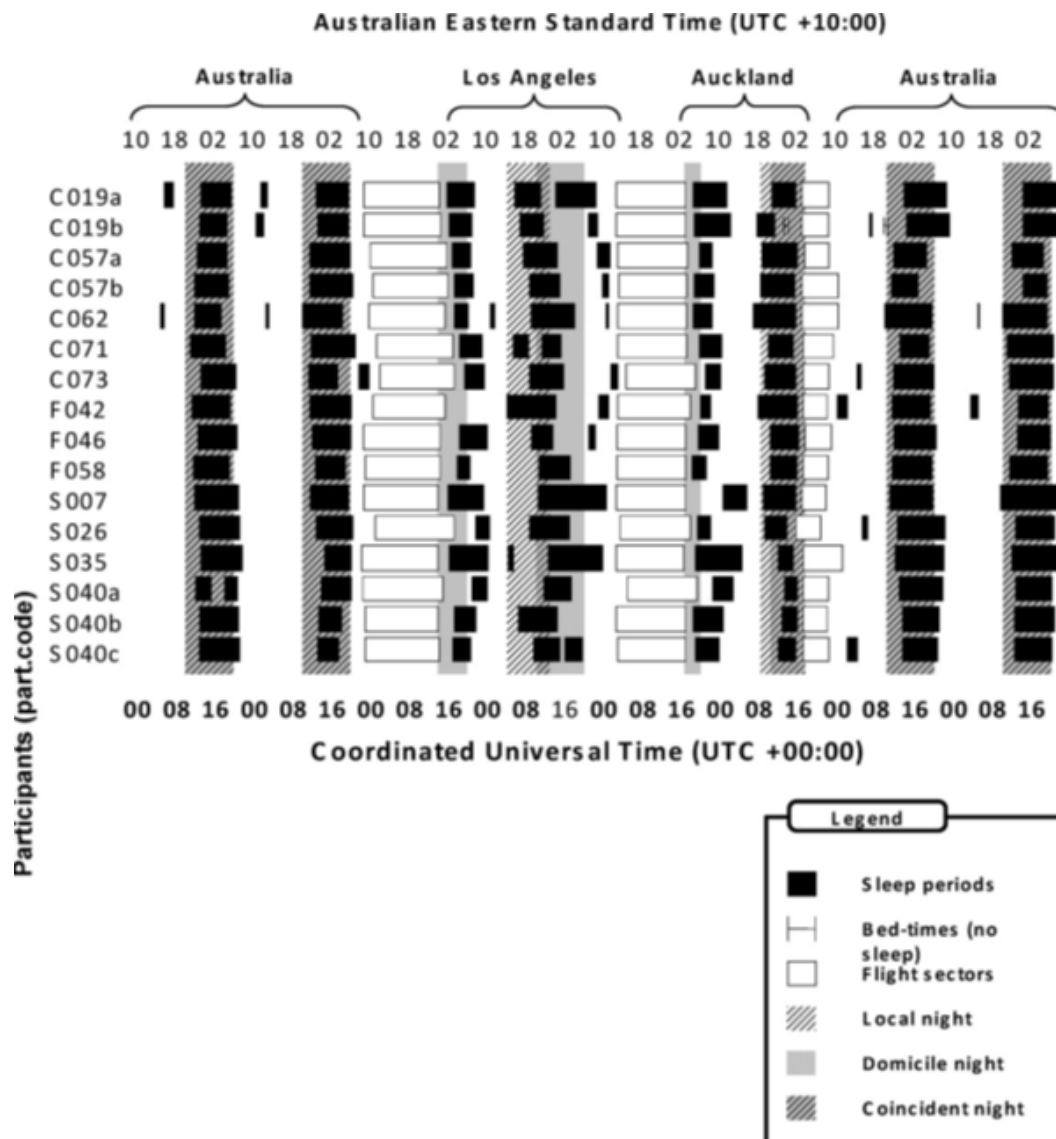


Figure 4. Plot depicting flight and duty periods, bed-times, sleep periods and local and domicile night periods (21–07 h) that occurred ~48 h before, during and ~48 h after an eastbound flight and duty pattern. Bed-times are shown only where pilots attempted to, but did not actually fall asleep. They-axis indicates the participant id-where in the first character represents the participant rank (C = captain, F = first officer, S = second officer) and the three-digit numerical value represents a unique number for each participant. In-flight sleep periods are not shown. Sleep-wake times were determined using wrist actigraphy in conjunction with sleep diaries.

### 8. Conclusion and Recommendation

Bio-mathematical models of fatigue have aided us in the management of risks associated with fatigue in the workplace. At the time that the practical program of an organization has been settled, the organization would be able to predict with a powerful approach and negligible error the complex relations and sometimes invisible among patterns of work, sleep, wakefulness, fatigue associate with risk and prevent the occurrence of these at the time of manufacturing and work. These models are able to aid organizations and manufacturers in decision making according to suitable work patterns and minimizing the risk from errors related to fatigue. Even

though there are few limitations at the time of model practice, but with the implementation of the model with few weak points is far better than entirely refraining from it. Studies have shown that these models are able to help significantly for better management of fatigue risk in decision making. In the coming years, it is expected that we might witness an increase in the use of these models, therefore starting from the consequent researches we should focus overcoming the limitations mentioned in this article and improve the current models. Influence analysis of mathematical models of fatigue in managerial systems and safety in the workplace.

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