HUMAN FATIGUE MODEL AT ROAD TRANSPORT

Irfan Ullah

N-W.F.P University of Engineering and Technology,
Department of Mechanical Engineering Peshawar, Pakistan
e-mail: irfanullah@nwfpuet.edu.pk

Janusz Szpytko

AGH UST
Faculty of Mechanical Engineering and Robotics
Mickiewicza Ave. 30, PL 30-059 Krakow, Poland
tel.:+48 12 6173103,fax:+48 12 6173531
e-mail: szpytko@agh.edu.pl

Abstract

This paper presents detailed studies in relevance of fatigue. Diverse aspects of fatigue, like causality data, risk factors and consequences have enlightened to address proper fatigue mechanism. Fatigue is going to be major issue in Asia, and has brought many deaths annually. Fatigue is a process that starts with risk factors, moves on to subjective perceptions of and concludes with the consequences of fatigue. Driver fatigue is recognized as a major causal factor in accidents involving long-haul commercial drivers. Human operational performance and its relation with road safety is really great mean to understand in terms of technical and human behaviour.

Fatigue risk factors, sleep, noise and working schedule etc like are also reduced with specific solution and personnel limits. Human error is found a basic reason of fatigue and need to be addressed to public and concerned authorities. Mathematical model and field based data is highly appreciated to understand basic scenario of subject and accident. The best way to reduce fatigue is to address issues publically and improve system according to environment of transport. This paper presents an introduction to the human fatigue model formulation and its application using a conception of the discrete time process that is regenerative with respect to the renewal process. The model can be used to estimate the human fatigue according to partial and full rest.

Keywords: driver fatigue, human error, micro-sleep

1. Introduction

The spectra of injuries are insidiously taking a greater toll on human life and property worldwide. It is estimated that 10 million crashes occur and more than 5 million people die, of which 25% are due to road traffic crashes: app. 1.26 million peoples died in 2000. Overall 10-15 million people are injured every year in road traffic collisions. It is projected that globally by 2020 RTCs (*Road Traffic Crashes*) will account for about 23 million deaths and RTIs (*Road Traffic Injuries*) will be the third leading cause of death and disability as compared to their present ranking of ninth. In Pakistan there are about 26 deaths from road traffic accidents per 100,000 populations, compared to Europe where the death rate averages is 14.5 per 100,000.

On a regional basis, road fatality takes the greatest toll on the Asia and Pacific region where 44 percent of the world's road fatality occurs and only 12 percent of the total occurs in Central/East Europe (Fig. 1).

Driver fatigue is one of the biggest safety issues facing the road transport industry today and the most dangerous aspect of driver fatigue is falling asleep at the wheel. Fatigue leads to sleep and lack of sleep are one of the leading causes of fatigue. Research has determined that inadequate period of rest, continuous work and loss of alertness play role in driver fatigue.
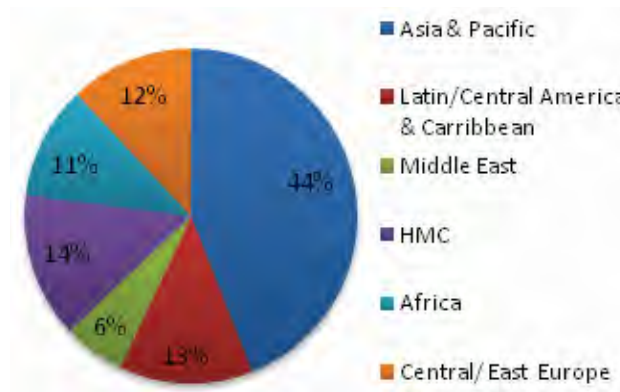
Fig. 1. Estimated Road fatality regional distribution (1999)

As the most important health and safety issue facing the sector today, it must be addressed so as to improve working conditions for drivers, but also to protect the public from the possible negative consequences which fatigue can induce.

Governments, employers and workers are all working towards combating fatigue through various means. These efforts should be encouraged and strengthened through social dialogue in order to improve the situation.

Transport is basic need of major industries, like oil and gas, refineries, cement etc. and these industries can also take better policies against human fatigue.

2. Human error and fatigue at road transport

One of the most important factors influencing of road safety is the human error. Human error is not random, for example, exhaustion at the end of an arduous watch, but may approximate to component wear out. Human error can also be systematic, for example the wrong training repeatedly leads operator to make the same mistake. But humans can cause problems for numerous other reasons, like by sabotage, acting on a whim, making decisions based on inadequate or incorrect information, and well-intentioned violation of rules. Thus, make modelling of human behaviour not trivial. Global concern with the extent of fatigue and its potential environmental cost is widely evident across the world. Human error depends mostly on: crew knowledge, experience, stress, mental and physical exertion, safety systems.

Driver fatigue can be subcategorized into sleep-related (SR) and task-related (TR) fatigue based on the causal factors contributing to the fatigued state. Sleep deprivation, extended duration of wakefulness and time of day (circadian rhythm effect) affect SR fatigue. The circadian rhythm also produces an alertness dip in the early afternoon during which people are sleepier.

TR fatigue is caused by the driving task and driving environment. Driver fatigue can be produced by active or passive TR fatigue. Active fatigue is the most common form of TR (*Task related*) fatigues that driver's experience. Examples of high task demand situations include high-density traffic, poor visibility or the need to complete an auxiliary or secondary task (i.e. searching for an address) in addition to the driving task. Passive fatigue is produced when a driver is mainly monitoring the driving environment over an extended period of time when most or the entire actual driving task is automated. Passive fatigue may occur when the driving task is predictable.

Most studies of driver fatigue focus on sleep deprivation or circadian rhythm effects, but require drivers to perform driving tasks during monotonous, highway conditions. This confounds the effects of SR and TR fatigue. Regardless, it is clear that driver fatigue does produce performance decrements in driver simulation and on-road driving tasks. Fig. 2 illustrates the three types of fatigue, their causes, consequences and interactions.
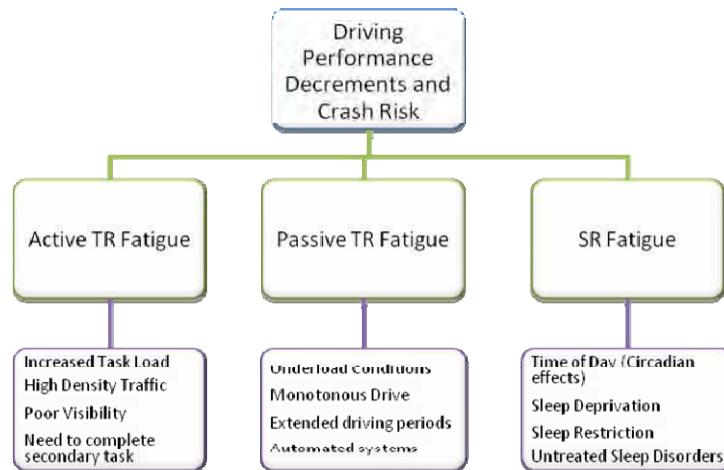
Fig. 2. A model of fatigue

3. Fatigue and the professional driver

Professional drivers regularly deliver freight and passengers over long distances. Evidence suggests that these drivers present an increasing problem for road safety. They may be at risk from fatigue, because generally they are not free to determine their work schedules, which often involve irregular hours of work. The irregular shifts may force them on occasions to continue driving during troughs in their circadian rhythm, so that performance may decline to sub-optimal levels. Irregular work schedules will also negatively influence the periods available for rest and sleep. Based on a review of 2000 commercial drivers and an in-depth study of 18 drivers for several weeks attributed driving fatigue to irregular schedules and work demands placed on commercial drivers. They believed accidents were directly related to the development of fatigue.

A review on truck and bus driver fatigue showed that irregular driving schedules produced greater subjective fatigue, physiological stress and performance degradation than did regular work hours. The influence of irregular schedules and physical work on the performance and fatigue of commercial drivers (with emphasis on bus and truck drivers) may be summarized as follows:
- irregular schedules cause greater subjective fatigue, stress, and performance degradation than regular schedules,
- pairs of truck drivers engaging in round-the-clock sleeper operations show earlier and/or greater signs of fatigue than single drivers,
- heavy cargo handling as well as long driving stints increases fatigue,
- during irregular operations the driver must at some time drive during those hours of the night when circadian reduction in physiological arousal are substantial,
- furthermore, professional drivers with irregular schedules do not always obtain 8 h of continuous sleep.

4. Human fatigue factors

Sleep provides the human body and mind time to rest, recuperate and reenergize. Human fatigue is in a dynamic balance between two competing forces; forces producing fatigue and forces reversing the effects of fatigue (recovery). Fatigue cause negative changes at human alertness, reaction time, decision-making and communication that increase the probability of human operational error. There are huge potential consequences of fatigue at road: accidents, collision risk, poorer performance, economic cost and environmental damage.

A fatigued driver can actually keep his vehicle perfectly in the lane, provided the vehicle heading is coincidentally appropriate for the road curvature ahead. In our studies we found evidence for intentional short "naps" on straight road sections, on which the vehicle path was

perfect, but the driver was incapable to react upon any unexpected event (e.g. front end collision). In order to prevent these dangerous situations of "good" lateral control without reaction readiness, more complex drowsiness detection techniques need to be developed."

Fig. 3. Fatigue process

Fatigue is a process that begins with risk factors, moves on to subjective perceptions of and concludes with the consequences of fatigue. Fatigue is defined by three outcomes: subjective perceptions, performance and physiological change.

Fatigue may be induced by a number of factors: lack of sleep, long working hours, working at times of low alertness, insufficient rest between work periods, excessive workload, noise and vibration, motion, medical conditions and acute illnesses (Fig. 4). Chronic fatigue can either be due to repeated exposure to acute fatigue or can represent a failure of rest and recuperation to remove fatigue (Fig. 5).

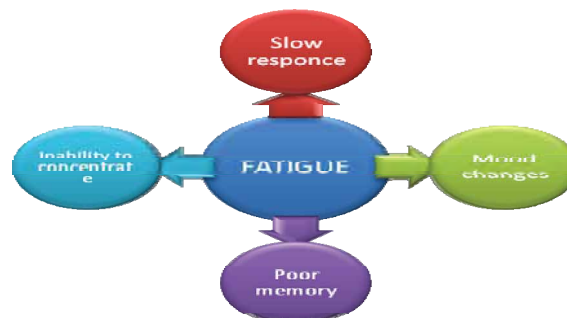*Fig. 4. Main fatigue risk factors*

Fig. 5. Fatigue consequences

Driver fatigue is recognized as a major causal factor in accidents involving long-haul commercial drivers. The development of an on-board driver performance/fatigue monitoring system could potentially assist drivers in identifying the onset of fatigue. Commercial drivers identified several important factors that drivers felt to be fatigue-related, including: work schedule, daily hours worked, trip length, cab environment (e.g., poor ventilation, noise, vibration), traffic volume (excessively high or low volumes of traffic), weather (e.g., bad weather, glare from sun).

There is extensive evidence from both laboratory and field studies showing that acute fatigue is associated with impaired performance and compromised safety. The main consequence of fatigue is increasing of mean error level that leads directly to the casualties. There are many recorded casualties in which fatigue were main reasons, but there is no information how many not recorded accidents coincides with fatigue.

5. Models [1-9]

5.1. Human rest and fatigue model

In recent years increasing attention has been focused on the effects of fatigue on human performance as part of the study of the causes of human operational error. Fatigue is a recognized operational hazard. There are few assumptions in the modelling:
- only human operational errors are considered,
- human errors are mutually independent,
- human errors occur randomly, with a certain probability distribution.

Consider a partial rest event, and let $W1$, $W2$... be the time between its successive occurrences (frequency), then:

$$S0; \; Sn+1 = Sn + Wn+1, \; n \in N. \tag{1}$$

Define the times of occurrence assuming that the time origin is taken to be an instant of such an occurrence. The sequence $S = \{S_n; \; n \in N\}$ is called a renewal process provided that $W1$, $W2$... be nonnegative random variables. Then the S_n's are called renewal times.

A renewal process S is said to be recurrent if $W_n < \infty$ almost surely for every n; otherwise S is called transient. S is said to be periodic with period $\delta > 0$, if the random variables $W1$, $W2$... take values in a discrete set $\{0, \delta, 2\delta \ldots\}$ and δ is the largest such number. Otherwise, if there is no such $\delta > 0$, S is said to be a periodic.

Consider o stochastic process $Z = \{Zt; \; t \geq 0\}$ with state space E. Suppose that every time a full rest occurs, the future of the process Z after that time becomes a probabilistic replica of the future after time zero. Such times (usually random) are called regeneration times of Z, and the process Z is then said to be regenerative with respect to the renewal process:

$$S = \{Sn; \; n \in N\}. \tag{2}$$

Let Tp denote the time interval between two operator activities. In this interval of time, only two kinds of events are considered. The type 1 is a partial rest, which restores operational ability to the level before action, and the type 2 is full rest that fully restores human's operational ability. When a rest event takes place, it will be an event of type 1 with a $p(t)$ probability or of type 2 with a probability of:

$$q(t) = 1 - p(t). \tag{3}$$

In another term, the probability of full rest is expressed as follow:

$$p1e \, (t) = p(t) \in pe(t), \tag{4}$$

and the partial rest probability is:

$$q2e \, (t) = (1-p(t)) \cdot pe(t), \tag{5}$$

where $pe(t)$ is the rest event appearance probability.

5.2. Asymptotic approach

Consider an operator which can be in one of two states, namely 'Active' it means in watch operational conditions and 'Rest' it means in rest conditions. By 'Active' we mean the operator is

functioning after rest period and by 'Rest' we mean the operator is having rest period. The state of the human can be given by the binary variable:

$$X(t) = \begin{cases} 1 & \text{for Active at time } t, \\ 0 & \text{for Rest at time } t, \end{cases} \tag{6}$$

An important characteristic of human operational ability condition is activity time. The activity time at time t is defined by:

$$A(t) = P(X(t) = 1), \tag{7}$$

The activity time model is developed under the assumption that the rest time is not negligible. Each time when the rest time starts it is partial rest (minimal rest) with probability $p(t)$ or full rest with probability $q(t) = 1 - p(t)$ where t is the time of journey. Let Vi be the time of the completion of ith rest period, i = 1,2, ... Define Ni as the number of minimal rests in the ith renewal period and $r(t)$ as the rest rate function. Let Ti,j be the time of journey which had $i - 1$, $i = 1, 2, ...$ full rest times periods and $j - 1$, $j = 1, 2, ...$ minimally rest periods after the time of the $(i - 1)$th full rest period. Let $F(r)j(x)$ be the conditional distribution function of Ti,j given $Ni = r$. Let assume that the times for period of partial (minimal) rest are identically distributed with the distribution $G1(y)$ and mean $v1$ and the times for period of full rest have the distribution $G2(y)$ and mean $v2$. Furthermore we assume that rest times are finite with probability 1. If the $p(t)$ and $r(t)$ are such that:

$$\int_0^\infty p(x)r(x)dx = \infty. \tag{8}$$

Then the steady state activity time $A = \lim_{t \to \infty} A(t)$ exists and is given by the formula:

$$A = \frac{\int_0^\infty \exp\left\{-\int_0^t p(x)r(x)dx\right\} dt}{\int_0^\infty (1 + v1 q(t) r(t)) \exp\left\{-\int_0^t p(x)r(x)dx\right\} dt + v2} \tag{9}$$

5.3. Cox proportional hazard model

A number of human error models and frameworks have been developed to understand the main causes of the human errors in accidents. All models have successfully accounted for contribution of human performance to overall risk and reliability and allow quantification of human error probability. Some of them have been applied extensively to nuclear power plants and to the space domain.

An objective of survival analysis is to identify the risk factors and their risk contributions. The Cox model is a statistical technique for exploring the relationship between the survival of a human and several explanatory variables. The Cox proportional hazards model was developed with person operational error as the effect of human fatigue.

The Cox model provides an estimate of the fatigue effect on survival after adjustment for other explanatory variables. It allows us to estimate the hazard (or risk) of human operational failure, or other event of interest, for individuals, given their prognostic variables.

Interpreting a Cox model involves examining the coefficients for each explanatory variable. A positive regression coefficient for an explanatory variable means that the hazard is higher and thus the prognosis worse, for higher values.

The Cox proportional hazard model is a semi parametric model which makes no assumptions about the form of h(t) (nonparametric part of model) but assumes parametric form for the effect of the predictors on the hazard. The Cox model can be used if we are more interested in the parameter estimates than the shape of the hazard. Parameter estimates in the Cox model are obtained by maximizing the partial likelihood. Parameter estimates are interpreted the same way as in parametric models, except no shape parameter is estimated. The Cox's model is represented as:

$$h(t) = h_0(t) \cdot \exp\left\{\sum_{k=1}^{n} \beta_k X_k\right\}, \tag{10}$$

where:

$h(t)$ - the hazard function,

$h_0(t)$ - the baseline hazard function,

$\beta 1, \ldots, \beta p$ - parameters to be estimated.

The hazard function is the probability that an individual will experience an event (operational error) within a small time interval, given that it not happened up to the beginning of the interval. A statistical technique called regression can be used to describe the relationship between the values of two or more variables. When more than one explanatory *(Xk)* variable needs to be taken into account we have a multiple regression.

Cox's method is similar to multiple regression analysis, except that it allows us to take more than one explanatory variable into account at any one time (for example, age, trip duration and number of partial fatigue period). The quantity $h_o\ (t)$ is the baseline hazard function, and corresponds to the probability of operational error when all the explanatory variables are zero. The Cox model must be fitted using an appropriate computer program. Cox Proportional Hazard Model:

- makes no assumptions about the shape of the hazard function,
- assumes that changes in levels of the independent variables will produce proportionate changes in the hazard function, independent of time.

The following factors should be taken as explanatory variables: stress resistance, mental state, social atmosphere, workload, mental strain.

6. Conclusion

The management of fatigue in order to reduce the likelihood of human error occurring at road is critical. Factors used to examine the role of human fatigue in accident investigations might provide a useful scheduling template to help avoid fatigue-related crashes. Lack of sleep, long working hours and working at time of low alertness, insufficient rest between work periods, excessive work load, noise and vibrations are the main factors that can cause human fatigue. When a person is affected by fatigue, his or her performance on the job can be significantly impaired especially at decision-making, loss of alertness, difficulty keeping eyes in focus, frequent yawning, loss of concentration and wandering thoughts, reduced awareness of surroundings, memory lapses, failure to check rear view mirrors as frequently as normal, unconscious variations in speed, erratic changing, drifting out the lane and countless other skills.

Lack of sleep is considered to be one of the primary causes of fatigue. If a sleep debt becomes too large, the brain will eventually go to sleep involuntarily. Challenges lie ahead for working time in road transport sector. There is a need to limit excessive hours for work and irregular working hours, and to provide for adequate periods of rest in order to protect the health and safety of road transport workers and the public. Understanding the sources of fatigue and the overall effect that it has on the performance of any driver makes introduction of countermeasures to help manage this fatigue to an acceptable level.

This paper presents an introduction to the human fatigue model formulation and its application using a conception of the discrete time process that is regenerative with respect to the renewal process. The model can be used to estimate the human fatigue according to partial and full rest.

Acknowledgements

References

[1] Krug, E. G., Sharma, G. K., Lozano, R., *The global burden of injuries*, Am. J. Public Health; No. 90, Vol. 2, pp. 523-6, 2000.

[2] World Health Organization, *A 5-year WHO strategy for road traffic injury prevention*, Geneva, 2001.

[3] http://www.car-accidents.com/country-car-accidents/pakistan-car-accidents-crash.html.

[4] Monk, T. H., *Circadian aspects of subjective sleepiness: A behavioral messenger?*, In: T.H. Monk, Editor, *Sleep, sleepiness and performance*, John Wiley and Sons, Chichester; New York, pp. 39-63, 1991.

[5] Desmond, P. A., Hancock, P. A., *Active and passive fatigue states*, In: P.A. Hancock and P.A. Desmond (Editors), *Stress workload and fatigue*, Lawrence Erlbaum Associates, Inc., Mahwah, pp. 455-465, 2001.

[6] Hartley, L. (Ed.), *Fatigue and Driving*: *Driver Impairment, Driver Fatigue and Driving Simulation*, Publisher: Taylor & Francis, Inc. Pub., 1995.

[7] Miller, J. C., Mackie, R. R., *Effects of irregular schedules and physical work on commercial driver fatigue and performance*, In: Oborne, D. J., Levis, J. A., Editors, 1980, *Human Factors in Transport Research*, Academic Press, pp. 127-133, New York 1980.

[8] Mackie, R. R., Miller, J. C., *Effects of hours of service, regularity of schedules and cargo loading on truck and bus driving fatigue,* Human Factors Research Inc. CA, Technical report 1765-F, 1978.

[9] Belz, S. M., *An On-Road Investigation of Self-Rating of Alertness and Temporal Separation as Indicators of Driver Fatigue in Commercial Motor Vehicle Operators*, Virginia Polytechnic Institute and State University, Ph.D. Thesis 2000.