A Benchmarking of the Integrated Train Driver Performance Model

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Abstract. Human factors / ergonomics (HFE) focuses on the interaction of human with the environment. The traditionally concept of HFE has always focused on the interrelationship between three main elements of human-machine-environment. Therefore, significant to this research was that an integrated Malaysian train driver performance model has been successfully developed for identifying the significant factors that influence train driver performance, highlighting the interaction between human factors, human activities and its context. There are a number of models and frameworks in existence, designed to fulfil the various contexts of particular research. This newly developed model was compared with past models from the previous researches. Through this benchmarking approach, this study has looked at the significant factors in holistic and comprehensive perspective without ignoring other potential domains of factors. In conclusion, the previous referred models mostly from the UK and Australia addressed similar arising issues of their train drivers. Fatigue, driving activity and sleepiness were among factors mostly investigated. Yet, the characteristics of the performance were similar between Malaysia, UK and Australia. However, this integrated model provides better and more complete model evaluating human performance.
objectives remained the same, which is to improve the performance and the well-being of employees by integrating human into a better system [6].

Performance is an important aspect for the industry, and is a priority to be achieved either by an individual or an organisation especially in handling complex tasks or working in demanding situations [7]. Job performance is a valuable element and an important dependent variable for achieving high quality work output and services [8]. To remain competitive and maintain a high level of job performance, the employee itself is the main focus to be taken care of [9].

Performance of the employee and the system is important in the transportation industry, especially in public transportations, where high performance of the organisation would result in increased safety conditions [10]. Ignorance of the performance of employees may lead to undesirable results. Accidents in the transportation industry frequently occur especially on the road. However for the railway, ships and aviation industries the frequency of accidents is very low [11] although the occurrence of accidents usually results in a large number of injuries, casualties and devastations. Thus, it is in the interest of these industries to seriously maintain high work performance, improve the safety levels and awareness to avoid catastrophes [12]. HFE has been increasingly accepted as an important tool to improve human performance and safety at every level, to ensure a safe transportation system [13, 14].

Past studies on evaluation of train driver performance has mostly focused on only one or very few relationships between influencing factors. There is yet to be any effort in integrating these influencing factors, with no studies conducted for train drivers in Malaysia. This paper will attempt to address the integrated developed model on Malaysian train driver performance and the comparison between existing models available around the globe.

2. Human performance in the railway system

The train driver is amongst the most important group in the railway system. In Malaysia, even with the introduction of electric trains in 1995, the responsibilities and functions of the drivers are still important. Among the challenges faced by train drivers today are the increasing number of train services on single or double tracks with a variety of freight trains, passenger trains, electric commuter trains and fast electric train (Electric Train Service – ETS). These require increased attention of the driver and the crew to avoid any difficulties or accidents throughout the train journey. However, studies on human performance in the railway industry are still in its infancy in Malaysia, and literatures on the subject are thus unavailable. For this reason, most of the literature review for this paper has relied on literatures from other countries, especially from western nations.

Performances of workers are important for the designers or engineers during the design or improvement of equipment’s, interfaces, jobs or systems [15]. Understanding of the human performance is not only done when the system is in place and working, but can be as early on in design stage, which may reduce the potential of error and improve the design, safety and effectiveness. Human performance in ergonomics is not limited to safety, comfort and satisfaction. It can support the reputation of the organisation, and its business strategy to stay competitive and sustainable [16].

In the railway industry, error-free operation is very critical to ensure the safety of the system. Circumstances from any train-related accidents would incur high costs and damage [11]. Railway safety does not focus on the train locomotives only, but also expands on aspects of the passengers, track staff, control room staff and other relevant staff. Train drivers are one of the important stakeholders for ensuring safety of passengers, the train locomotives and the system [17, 18]. A landmark train accident in Ladbroke Grove in 5th October 1999, with 400 injuries and 31 deaths, has triggered an extensive evaluation of railway safety in the UK. It was reported that human error was the
main cause of the accident, due to signal passed at danger (SPAD) and the subsequent head-on collision events [19]. Although rail ergonomics is evolving slower than other branches of transport ergonomics [17], there is an increase in the level of awareness on the importance of human factors in the railway industry, and is very crucial for improving system reliability, safety and human performance [13].

Human capabilities and limitations are the main factors which would contribute to the safety of the individual and the system. These factors should be considered during early stages of the design; corresponding to the needs, knowledge and characteristics of the workers [20]. Improvements may be delayed if there is lack of understanding on human performance of the organization [21]. Human performance measures are required to be used as a predictor in addressing the increasing demand for improvements in system and safety, or as an objective tool to evaluate the need to improve the design of work, equipment and the environments.

Table 1 shows a list of thirty two previous studies over the past twenty five years on human performance in railway since 1986. At least seventeen factors affecting the performance of train drivers were discussed in these studies.

**Table 1: Previous studies on factors relating to human performance in rail.**

| Variables | Cognitive | Mental workload | Physical workload | Alertness | Awareness | Stress | Working task | Vigilance | Fatigue | Environment | Working conditions | Sleep | Shift work | Job rotation | Safety culture | Human performance |
|-----------|-----------|-----------------|-------------------|-----------|-----------|--------|--------------|----------|---------|-------------|-------------------|--------|-------------|--------------|-----------------|--------------------|
| 1         |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 2         |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 3         |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 4         |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 5         |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 6         |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 7         |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 8         |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 9         |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 10        |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 11        |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 12        |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 13        |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 14        |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 15        |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 16        |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 17        |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 18        |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 19        |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 20        |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 21        |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 22        |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 23        |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 24        |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 25        |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 26        |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 27        |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 28        |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 29        |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 30        |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 31        |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
| 32        |           |                 |                   |           |           |        |              |          |         |             |                   |        |             |              |                 |                    |
Each article have at least discussed two or more factors, except some studies which have deliberated on the general safety and human performance as the main discussion. Interrelations between factors on the performance of the driver were also discussed in order to further understand the influence of factors on one another.

It shows that safety / safety culture was the predominating factor discussed by the researchers (12 out of 32). As highlighted previously, the level of safety is crucial and will always be the highest priority in the railway industry. Three studies have exclusively discussed on safety [22-24]. They highlighted the importance of the safety culture to reduce the risk of accidents and to improve the level of safety in the organization. Other researchers have examined the relationship between the safety and shift work of the train driver. Joshi, Kaufman [25] have studied the interactions of the train driver's reaction towards the train control system in shift work; and its potential for safety risk. Researchers were also interested to evaluate human performance in relation to the interactions of safety with other factors.

Hamilton and Clarke [26] proposed a model to describe performance of the driver in relation to infrastructure features and operational conditions. Through the proposed model, driver behaviour could be predicted by using performance times for discrete actions. It had also utilised cognitive task analysis (CTA) to predict workload and operator performance time. This study was focused on cognitive and mental workload of the driver. It was hoped to identify human performance problems for the train driver empirically.

3. The Performance Model

In this study, fourteen factors were initially evaluated by hypothesis testing, from which seven factors were identified to be significant [55]. Table 2 lists the seven factors which influence the performance of train drivers in Malaysia, which are job-related tension (internal conflict), fatigue, occupational stress, driving task, work environment, working condition and safety. The integrated performance model of Malaysian train drivers is presented graphically in Figure 1.

Table 2: Factors affecting performance of the Malaysian train drivers

| Domain | Hypothesis |
|--------|------------|
| Human  | H1: Occupational stress in Malaysia |
|        | H2a: Job related tension (internal conflict) |
|        | H4: Fatigue |
| Activity | H7: Driving task |
| Context | H9a: Safety culture |
|        | H10: Working condition |

*(Factor) has a significant effect on the performance of train drivers*
Figure 1: Malaysian train driver integrated performance model

The integrated train driver performance model was developed based on SEM-PLS algorithm, utilising shapes (oval and rectangles) and arrows to show the relationship between constructs and indicator variables [56-58]. A simplified representation is shown in Figure 2, consisting of 3 concentric circles.

The innermost circle is the main objective of the study on the performance of the train driver. The outermost circle is divided into three to indicate the three domains influencing the performance of the train drivers, which are human, context and activity. The middle circle represents the factors which affects the performance of the train driver. For clarity, the colour schemes for the factors are chosen to be similar to their respective associated domain. This middle circle is dynamic, meaning that for future studies; factors can be inserted or removed to suit the circumstances of that particular study. However, the factors added would still be grouped under the three major domains. The simplified version of the integrated Malaysian train driver performance model is deemed to be easily understood by the general public and could be used as guidance for the management and stakeholders in managing human capital in the TOC.

Figure 2: An integrated Malaysian train driver performance model
4. Benchmarking of the model with other related studies

There are a number of models and frameworks in existence, designed to fulfil the various contexts of particular research. This newly developed model can be compared with past models from the literatures. Table 3 shows an overview of the comparison between the proposed model of this study with other existing models and literature on train drivers from around the world.

The comparison is made based on several details. The first column of table shows the authors and the year the article is published, to indicate the timeline of the study. The table also shows brief descriptions of the model or framework, the measurement methods and its sampling factor. The most important comparison is the key indicators selected for each particular model or framework. The comparison can be made on the choice of factors for the domains of human, activity or context.

In most models, the ‘human’ domain was the main focus and interest, indicating the preferential importance of ‘human’ in performance study of employees. However, ‘human’ is a domain containing a large number of factors, inclusive of cognitive, job satisfaction, and gender. Fletcher and Dawson [59] has developed a work-related fatigue model of 193 train drivers in the UK, focusing on fatigue by evaluating sleepiness and alertness using sleep / work diaries and fatigue model due to hours of work. The emphasis was on physiological factor, i.e. sleepiness and fatigue with relation to hours of work. Performance of the train driver was measured through alertness level and objective performance test (OSPAT). However, this model did not consider the environmental factor (context domain).

Two other models related to railway have focused on the cognitive performance of the train driver; and its relationship with work environment and job-task. In 2005, Hamilton & Clarke [26], through their Cognitive Task Analysis (CTA) model, investigated cognitive ability of the train drivers in the UK and their reaction with signals and signs along the track to check on signal pass at danger (SPAD) scenario. Similarly, McLeod, Walker [34] have also studied cognitive aspect of train drivers in the UK, focusing on Automatic Warning System (AWS) which was also related to SPAD scenario. These two research work had focused on the cognitive response of the train driver while driving to reduce SPAD incidents.

Six articles from Australia had focused particularly on fatigue of the train drivers. Lamond, Darwent [36] studied alertness of fifteen train drivers of Adelaide – Melbourne relay trip by assessing their sleepiness through activity monitoring and sleep diary. Dorrian, Roach [42] have used simulation studies to evaluate the alertness of the train drivers and their fatigue levels. The study was further extended in 2007 to relate fatigue and alertness with incorrect response of cognitive disengagement towards safety of the train driving. Jap, Lal [60] also conducted a simulation study of fifty male train drivers to investigate fatigue using EEG (electroencephalography) activity monitoring. Darwent, Lamond [48] have studied on the sleepiness and performance of the long relay train drivers between Adelaide and Perth, focusing on the relationship between sleep and performance of the train drivers. In addition, the work environment and their working condition were also considered. Although three basic influential domains were addressed, it had only considered certain criteria, i.e. sleepiness (human), driving, work environment and working condition. Fatigue during extended rail operations was also investigated by Jay, Dawson [47], which utilised a 5-min response task (RT) and 7-point Samn-Perelli Fatigue Checklist on nine male drivers. From the six articles on the evaluation of Australian train drivers, five studies have centred solely on fatigue of the train drivers, using either simulation study or actual driving, focusing on long-haul train operations. Another study was examined sleepiness of the train drivers and its relationship with their driving activities, work environment and working condition. The limitations of these past studies were the sole focus on only fatigue or sleepiness, without consideration to other factors which may also influence the performance
of the train drivers. The absence of consideration for other factors can misdirect the research direction and may result in inaccurate conclusions in investigations involving human performance as a whole.

Table 3: Benchmarking of the integrated model with previous literatures

| Authors | Brief description | Measurement method | Target group, sample | Human | Domain | Activity | Context |
|---------|------------------|---------------------|----------------------|-------|--------|----------|---------|
| Fletcher and Dowson [59] | Field-based validation of a work-related fatigue model | Sleep/work diaries, wore actigraphs | 150 train drivers | Sleepiness | UK | Fatigue | Activity and safety |
| Hamilton & Clarke [20] | CTA Model | Train driver performance in interaction with infrastructure features | 235 train drivers | Cognitive | 24 scenarios of AWS usage | Driving | Infrastructure |
| Caponecchia [55] | Developing a checklist | Long speed on driver interaction with signals and signs | 150 train drivers | Cognitive | UK | Driving | Infrastructure |
| Baysari, Jay, Dawson [47] | Integrated train driver performance model | 37-items questionnaire | 220 respondents | Occupational stress | Malaysia | Work (driving) task | Work environment |
| Dawson [59] | Drivers’ sleep and alertness during short relay operations | Activity monitor | 13 drivers | Sleepiness | Auckland – Melbourne relay trip | Alertness | Driving |
| Dorrian, Roach [42] | Effects of fatigue on train handling during speed restrictions | Simulation driving | 50 male train drivers from Queensland depots | Fatigue | Australia | Alertness | Driving |
| Dorrian, Roach [45] | Effects of fatigue increasing deficiencies and accident risk | Simulation driving | 180 train drivers | Fatigue | 20 scenarios of AWS usage | Alertness | Driving |
| Hamilton, Lamond [48] | Sleep and performance of train drivers during an extended freight-haul operation | Mini-Miller Actigraph, task monitoring devices to assess sleep/wake states | 10 male train drivers | Incorrect responses | Australia | Fatigue | Driving |
| Jay, Dawson [47] | Fatigue during driving | Fatigue model | 9 male drivers | Fatigue | Australia | Alertness | Driving |
| Bayram, Caponecchia [61] | Review of 40 rail safety investigation to understand contribution of HFE to railway accidents | EEG activity monitoring | 20 male train drivers from Queensland depots | Fatigue | Australia | Alertness | Driving |
| Sap, Lai [50] | Comparison of EEG activity among train drivers during monotonous driving | EEG activity monitoring | 50 male train drivers | Fatigue | Australia | Alertness | Driving |
| Jalil Azlis-Sani [55] | Integrated train driver performance model | 27-items questionnaire | 220 respondents | Occupational stress | Malaysia | Work (driving) task | Work environment |

Only one literature did a review of forty rail safety investigations; to understand the contribution of human factors and ergonomics (HFE) to railway accidents. This literature was absolutely discussed on accidents and safety of the rail industry in Australia.

Subjective measurements are often used in investigation involving performance of workers. The technique is widely used in ergonomics study to understand certain issues in human factors, although whether the approach is acceptable as scientific measurement has been a topic of debate [62]. Nevertheless, there are several objective measurements methods that have been used in ergonomics study [63], although their applications have been very limited especially on the number of respondents
to be measured. An example of the use of objective measurements is the application of Electroencephalogram (EEG) signals to investigate mental fatigue [60, 64]. However, in this study; subjective measurements were mainly used, utilising the paper-pencil questionnaire survey to gather information from 229 train drivers.

In contrast to previously developed models, the proposed model in this study presents an integrative model. The three main domains of human, activity and context were identified from past literatures and have been evaluated thoroughly. Occupational stress, job related tension and fatigue were the results of improper task-design and poor work environment and working conditions. These factors were investigated simultaneously to study its relationship with the performance of the train driver. In addition, this model includes consideration of the safety culture, whereas other models tend to study safety aspects separately. Thus, this model integrates the various important aspects and factors in a complete package for the evaluation of human performance. The model is characterising to be dynamic, in which factors can be customised within the three main domains to create an improved human performance study in HFE.

In conclusion, the previous referred models mostly from the UK and Australia addressed similar arising issues of their train drivers. Fatigue, driving activity and sleepiness were among factors mostly investigated. Yet, the characteristics of the performance were similar between Malaysia, UK and Australia. However, this integrated model provides better and more complete model evaluating human performance.

5. Conclusion

To date, it was found that an integrated model of train driver performance has yet to be fully developed, especially in Malaysia. This paper attempts to address this limitation by developing an integrated model of train driver performance, specifically for train drivers in Malaysia. This model will provide a comprehensive understanding of human performance by incorporating three main domains of human performance; human – activity – context. Past studies have evaluated these factors either individually or with limited interactions between the factors. It can then be subsequently used by researchers as an important reference point to venture into evaluating other affecting factors of human performance, in different area of studies. In addition, train operating companies (TOC) can utilise this framework as a guideline to improve the design of workplace and tasks, train infrastructure as well as raising the level of awareness among employees. This will ensure that the company remains profitable, competitive and safe, and maintains a high level of performance of employees and the organisation.

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