CHAPTER 1

INTRODUCTION

In this chapter the background to the study is provided and the existing research gap is defined. The justification and aims of the study is provided and a scientific hypothesis is postulated.

1.1 PROBLEM STATEMENT

The South African Rail Operator, Spoornet, was faced with a potential problem when, for safety and operational reasons, it decided to effect changes in its train control systems. The problem related to the capacity of operators to authorise trains safely and efficiently by means of a train control system traditionally used in areas of low traffic volume.

Spoornet operations currently use several train control systems, of which the colour light signalling system is used in areas of high traffic volume. This system has been in use in South Africa for over five decades. In recent years there has been a steep increase in the vandalism of lights and the theft of light and points cables on Spoornet property and infrastructure. This has rendered the colour light signalling system vulnerable and has posed a threat to safe rail operations. The risk to railway operations has therefore necessitated a re-evaluation of train control systems in certain areas and the consideration of a train control system that is less vulnerable.

Another factor that has increased the need to change to a different train control system is the significant decrease in traffic volumes in certain sectors and geographical areas. Colour light signalling is normally used in areas with high train traffic volumes. The system is expensive to maintain and lower traffic volumes do not require such a sophisticated train control system. The high cost of maintaining the colour light signals in view of the low traffic volumes rendered the system no longer viable in specific areas.

The Radio Train Order (RTO) train control system is an alternative system that is currently in use, and considering safety and economy, it was a logical choice for replacing the more vulnerable and expensive colour light signalling system. It was also considered the most suitable system because the Track Warrant System (TWS), a system developed and used in North America and one that closely resembles RTO, was at the time under consideration for implementation in South Africa.

However, changing to a different train control system is not a simple matter. There are operational factors that need to be considered before implementing a specific system, such as traffic density, the nature of the train service (passenger, goods and suburban trains), geographical factors (e.g., suburban vs. rural settings), and the availability and affordability of the requisite technology. There is also a need to consider the human operators who will be affected by the changes. This study was initiated in order to investigate and provide insight and guidelines as to how the human operator will cope with the workload potentially imposed by a change from colour light signals to radio train order.

1.2 BACKGROUND

A proliferation of control and display technology in modern systems can impose heavy demands on operators' information processing capabilities. Such technology often requires the rapid sampling and integration of a large amount of information. The resultant demands could approach or exceed the limited information-processing capacities of the operators. Consequently, the need to assess the load imposed on operators' processing capacities is particularly critical in high technology systems (Eggemeier, 1988).

Xie and Salvendy (2000) make the following comments about the sensitivity of multitask environments:

> It should be noted that handling of complex systems, such as flying an aircraft, monitoring a process-control facility and interacting with computing devices can often impose multiple, concurrent task demands on operators. Safe and efficient operation of complex systems requires that information-processing demands imposed on operators do not exceed their capabilities. Processing demands that exceed these

limits can lead to degradation in both operator and system performance. Assessment and prediction of the workload associated with multitask environments is, therefore, an important issue.

When assessing the control of complex systems by human operators it is essential to have some predictive model that will map system demands onto operators' capacities and determine the extent to which these demands exceed capacities. The explosion of modern computer and related engineering technology has led to a significant increase in the level of complexity, sophistication and degree of integration of operational train control systems. The role of the human operator has, in parallel, changed from what it once was. Many of the tasks that operators previously performed manually are now automated. The operator's role is increasingly changing to that of a system monitor, information manager and decision maker.

These developments are relevant to the Spoornet train control environment and emphasise the necessity for a tool that would allow for the assessment and prediction of mental workload in this multitask environment.

Train Control Officers (TCOs), also known as railroad or train dispatchers, are responsible for authorising the movements of trains within the context of a particular train control system on the South African Rail network. TCOs are trained in the specific train control system of the area where they work. For every train control system there is a predetermined methodology to be followed. Without an authorisation from a TCO, whether it is a green signal aspect (the railway term referring to the colour of a signal), an authorisation number, or a token or written authority, the train is not permitted to move. Thus, TCOs bear a high level of responsibility for safe train operations, with much similarity between their tasks and those of air traffic controllers.

Train dispatchers are critical control elements in the total train control system. They are responsible for both the efficiency and the safety of the operation. Their job is demanding; they are under almost constant pressure, regularly assessing complex combinations of information, making critical decisions and responding to unexpected complications. Their work environment is often far from ideal – uncomfortable, noisy and confusing (Devoe, 1974). Even thirty years after this description, the role of the TCO remains relatively unchanged.

Between 1999 and 2004 several accidents occurred in which the workload of the TCO was cited as a causal factor. In one of these accidents there was loss of life, and in the other accidents damages in the order of millions of rand were incurred. The damage to the reputation of Spoornet as a result of negative publicity was incalculable. These occurrences as well as changes in traffic volumes, and the theft and vandalism of signalling equipment have necessitated a reconsideration of the type of train control systems that might be utilised in future.

In the design of complex systems, a question that has been posed is whether the operator can perform the tasks required by the system in both normal and contingency modes. Human operator workload is a term used for describing the synthesis of task performance in both modes. One of the objectives of workload-related evaluation is therefore to confirm that the designated personnel can effectively operate, control and maintain the system (Cilliers, 1992).

Estimates of workload can determine whether specified functions and tasks allocated to human operators are feasible in terms of time and capability requirements. If demands exceed capabilities, performance may be severely compromised. If demands do not exceed capabilities, provision should be made for a sufficient margin of residual capacity or resources so that unexpected failures or environmental events may be handled to a satisfactory level (Wickens, 1992).

The issues raised by the two authors above – the ability to operate the system and the feasibility of task allocation in terms of operators' capabilities – are the gaps that this study aims to address.

1.3 RESEARCH GAP

In the absence of specific workload measurement techniques, this study was undertaken with the aim of developing a mental workload measurement and prediction tool that could be applied in the train control environment. The research problem is the objective measurement and quantification of TCOs' mental workload in order to compare the various train control centres in terms of workload and to predict the workload at a particular centre, given a certain set of conditions and variables.

The intended outcome of the study is to develop an objective method by which the mental workload of Train Control Officers (TCOs) can be measured and to develop a task-related index that can serve as an indication of actual or potential mental workload imposed on operators in specific work environments. In the railway environment, as in any safety-critical environment, mental overload can have potentially dire consequences.

The population, on which the mental workload assessment methodology was developed and tested, is Train Control Officers at Spoornet, the South African Railway Operator.

The objective of this research is the improvement of the performance and reliability of TCOs through the prevention of mental overload and ultimately therefore improving rail safety. In order to achieve this objective the following tasks were identified:

- Identify all possible factors that could contribute to the mental workload of TCOs.
- Develop methods to measure these factors.
- Verify the measurements to ensure validity and reliability.
- Develop an index to measure and predict mental workload that would stand the tests of objectivity and scientific scrutiny, and above all, contribute to a safe working environment.

1.4 JUSTIFICATION FOR THE STUDY

The proposed deployment of Radio Train Order (RTO) by Spoornet management as a means of train traffic control in specific areas has brought about a renewed focus on and examination of RTO by line management responsible for effecting changes in train control.

As a result, the shortcomings of the existing system have been highlighted. The main concern was that a previously set norm for the number of radio train orders that could be handled safely by TCOs existed. No documentation could be found that indicated the rationale for its development and the reasons for including only certain variables. The assumption was made, based on the elements in the formula used to calculate the norm, that it relates to the limitations of the technology rather than to those of the operators. There was also considerable uncertainty about the validity of the norm, as it was based on a purely mechanistic formula. Furthermore, there was concern regarding the replacement of an existing train control system with RTO while not knowing what the existing norm referred to or what it aimed to limit. It is a known fact, as explained before, that the decision to utilise a specific train control system is determined by a variety of factors. This automatically gives rise to the question: If the train control system is replaced by a different system (such as RTO), what guarantee is there that the new system will be suitable for the specific section? The underlying question from a human factors perspective is: Considering the change in workload, what guarantee is there that human operators in specific train control centres, with their own set of task demands, can safely operate RTO? In addition to this, what would be the safe norms within which to operate?

The following formula was used to calculate the workload of TCOs in the RTO environment. As far as can be ascertained, no studies were performed to prove the validity of this method.

Elements of the existing workload assessment method are:

i. Number of trains
ii. Number of train order stations
iii. Calculated over a 24-hour period

The formula used in terms of the above-mentioned method to calculate the workload of TCOs is:

$$\frac{\textbf{Number of Trains} \times \textbf{Number of Order Stations}}{\textbf{24}} \leq \textbf{100}$$

The norm that was set for a high workload was that if the calculated ratio exceeded 100, the workload was arbitrarily considered too high for that TCO. No rationale was provided for the threshold level of 100.

When analysing this formula, some issues were detected that support concerns about regarding the validity of the index:

- The fundamental problem with the current method is that it is calculated over a 24-hour period and does not consider the number or length of shifts. A 24-hour period can consist of two 12-hour or three 8-hour shifts.
- Different operators work different shifts and the number of trains are not evenly distributed over the shifts. The index above could measure some form of workload but it is not indicative of a single TCO's mental workload unless the number of trains and order stations are calculated per shift.
- As far as could be ascertained, the norm of 100 for a high mental workload has not been validated in any way. It is still not clear what constitutes a high workload.
- It is also not clear whether all the relevant factors that contribute to mental workload, such as a TCO's experience and the difficulty factors of the section they control have been included in the index.
- When applying this formula, a section with four trains over a 24-hour period and 100 order stations, and another section with 100 trains over a 24-hour period and four order stations gave the same workload rating. The perceived workload of the two scenarios was tested with a panel of expert users of RTO. They unanimously agreed that 100 trains with limited crossing places (four) compared with four trains and 100 possible crossing places would impose workloads on operators that are comparable to the extremes on a continuum.
- No scientific proof exists that existing method is valid (that it actually measures mental workload).

With analysis of the existing workload assessment method being used for train control officers at Spoornet, it becomes clear that its predictive, construct and face validity are questionable. The concern is raised that, while this method attempts to measure workload in the train control environment, it is possible that it does not measure the most pertinent factors that contribute to operator mental workload. Since the existing method is used as the norm for safe operations, this situation is potentially problematic for the employer, especially considering the legal requirements of employers in terms of employee and public safety (Occupational Health and Safety Act, 1993).

The Federal Railroad Administration (FRA) in the United States of America has performed a safety assessment of train dispatchers in 1987/88. During this exercise they collected data on the number of trains handled and the number of authorities issued by individual dispatchers over the course of a shift. This assessment considered the same elements as the formula used by Spoornet for calculating the workload at RTO centres. The FRA determined this to be an imprecise method of measuring dispatcher workload since it did not take into account the varied tasks that dispatchers must perform to move a train across the assigned territory (Popkin, Gertler and Reinach, 2001).

This study was conducted in an RTO control centre environment. Other train control systems in use on Spoornet infrastructure are the following:

- Colour Light Signalling System (Local Panel and Centralised Traffic Control [CTC])
- Radio Train Order (RTO) and Track Warrant System (TWS) (individually and in combination)
- Van Schoor System
- Semaphore Signalling System
- Telegraph Orders System
- Wooden Train Staff and Paper Ticket System

RTO-controlled sections interface with these other systems, which add to the complexity of the TCO’s task.

In the RTO environment, train orders are authorisations given by radio to train drivers to proceed to a predetermined point. Normally, these points are 14 kilometres (or less) apart. Contact is usually initiated by the train driver who needs to obtain an authorisation to pass a specific kilometre point and proceed to the next specified point. RTO is operated on a single track and all communication is conducted over the radio. All radio communications and telephone conversations are captured on a voice logger, which logs the date, time, content and duration of every conversation. The TCO’s function involves, among other things, planning daily train movements based on a given train schedule, making out authorisations, communicating with train drivers and dealing with telephone queries (normally of an operational nature). A track warrant is exactly the same as a radio train order, with the added safety feature of capturing train movements and authorisations on computer. The authorisation is then checked and approved by the computer. Authorisations which conflict are blocked by the computer and an authorisation to proceed will not be issued. TWS acts as a safety check for the actions of the TCO.

There are a variety of errors that can be made by TCOs. In the RTO environment these can be the misunderstanding of the position of a train, the issuing of an incorrect authorisation, or incorrect planning. These could lead to trains not crossing at the planned crossing places, and thus possible collisions.

With less equipment that could potentially be vandalised, RTO in combination with the added safety feature of the TWS seems to be favoured as the train control system for the future in South Africa. This would be especially true in areas where CTC is considered to be too vulnerable and expensive. It is foreseen that RTO will be expanded and introduced in more areas over the rail network in South Africa. For this reason an objective mental workload index is required in the train control environment. This type of index may prove valuable in other environments too, such as air traffic control and control room monitoring activities (i.e., nuclear installations).

In a paper delivered at the International Conference on Occupational Ergonomics in 1984, Moray (as cited in Meshkati, Hancock, Rahimi, and Dawes, 1995) made the following comments on the measurement of mental workload. These comments reflect the very same issues that Spoornet is faced with and that this study aims to address: (The italics are the author's own emphasis.)

> Paradoxically, the fact that the operator seems to be doing less and less as processes become automated has resulted in a greater need for a measure of workload.
>
> If all operators showed graceful degradation under load, the problem would not arise. But while some operators allow their performance to degrade progressively

as the load builds up, others appear to compensate for the effect of the load and show no change until a final catastrophic breakdown occurs. *In terms of safety requirements, if for no other reason, it would be highly desirable to have a metric for load which would allow one to detect the approach to the breakpoint independent of observable changes in performance. Such a metric does not exist***.**

This statement, by highlighting that there is still no workable index that measures mental workload in practice, clearly confirms the need for this study. The study areas of fatigue, stress and the other factors that contribute to mental overload have been studied and researched extensively but mental workload and specifically the measurement thereof, has many research gaps.

1.5 AIMS OF THE RESEARCH

The current unsatisfactory and potentially unsafe situation that Spoornet is faced with in determining the workload of TCOs working with RTO is not an isolated one. Similar scenarios are evident throughout the literature and the related comments echo the urgent need to develop a methodology with which to measure mental workload. This methodology needs to be validated and based on existing theories to ensure safe and accurate operations.

In short, the objective of the envisaged Mental Workload Index is to create a management tool that is proven to be valid and reliable and that can be applied to classify different lines or sections (this refers to the length of track that is controlled by a specific TCO before another TCO in the next train control centre takes over the movement of the train – the distance could range from under 100 kilometres to about 1000 kilometres) in terms of the mental workload these would impose on operators. This classification would assist in planning and allocating human and other resources, where and when necessary, and in taking the preventative steps necessary to minimise the risk of operator overload.

1.6 HYPOTHESIS AND RESEARCH QUESTIONS

The scientific hypothesis that will be tested by this research is:
The objective mental workload index as developed in this thesis can differentiate between high and low imposed workload train control centres.

In the process of developing the Mental Workload Index and eventually comparing the calculated workload at the various train control centres with physiological measurements associated with mental workload, the following research questions will be addressed:

- Which operator tasks could potentially be associated with mental workload?
- Which moderating factors, which would either increase or decrease mental workload should be considered and how can their respective moderating effects be determined?
- Which parameters should be considered to develop a measure of a mental workload that is completely objective and requires no estimation of experienced load by the operator?
- Can the proposed index differentiate between workload levels that could potentially be experienced at different train control centres?
- Which physiological measurements provide an objective assessment of mental workload?

1.7 OUTLINE OF THE THESIS

The contents of the thesis is organised in the following manner:

Chapter 1 – Introduction
In the Introduction the problem statement, research gap, justification for the study as well as the aims and the scientific hypothesis are provided.

Chapter 2 – Literature study
This chapter covers the elements related to mental workload research that could be found in the literature namely, the definition of mental workload, other related subject areas such as stress and fatigue, and the variables that affect mental workload. Mental workload

assessment techniques are discussed in detail and in closing, the study is contextualised in current railway related research.

Chapter 3 – Methodology

This chapter represents the essence of the study and provides a detailed account of the development process of the MWLI.

Chapter 4 – Results

The results of the verification study are discussed in this chapter. Key results are discussed but the full report is attached as Appendix D.

Chapter 5 – Discussion

The results are linked to the original hypothesis and possible applications of the MWLI are discussed.

Chapter 6 – Conclusions

Closing remarks are made and the limitations of the study as well as recommendations for further research are made.

Appendices

Appendix A - Cohen's Perceived Stress Questionnaire

The questionnaire was used in the pilot and verification studies to determine the perceived stress of Train Control Officers.

Appendix B - Timeline Analysis Template

The timeline analysis was used to capture the activities of Train Control Officers during the verification study.

Appendix C - Pilot Study Report

The study was undertaken to determine whether the physiological parameters rendered useful results.

Appendix D - Report on Validation Study

The verification study was undertaken to correlate the calculated Mental Workload Index with physiological parameters.