CHAPTER 3

METHODOLOGY

This chapter provides a detailed account of the development of the Mental Workload Index, which is the essence of this study. The chosen development approach and process is motivated and discussed after which a description of the specific steps that were followed to identify the factors to be included in the index and the allocation of weights to those factors, are detailed.

3.1 DEVELOPMENT APPROACH

The guiding principle in the approach was to develop a methodology that would provide an objective measurement of the 'pure', task-related mental workload factors that may be imposed on TCOs at specific train control centres. The methodology deliberately steers clear of assessing the performance of operators or the workload as subjectively experienced by specific train control operators.

However, because tasks are executed by human operators, it is difficult to isolate the individual from the task. Every attempt was made to adhere to the premise of identifying and measuring the task-related factors in the research design and in the development of the mental workload index.

A combination of quantitative and qualitative techniques was used in order to achieve the objectives of the study. The techniques include psychological and operational research techniques and physiological measurements.

For the proposed methodology to be successfully implemented and accepted by all relevant role players at Spoornet it was essential that they all formed part of the development process.

3.2 RATIONALE FOR THE METHODOLOGY

The model of Meshkati (1988) provides no guidelines as to which specific measurement techniques should be used for validation of mental workload in a context similar to that of this study. This lack of clarity as well as the lack of information on tasks and simulated environments in existing research, as confirmed by Cilliers (1992), as well as the conflicting research results referred to earlier, has lead to a problematic situation in the rail operational environment. The uncertainty and therefore the risk of using measurement techniques as described in the literature and then applying them to the context of rail safety, where operational decisions would be based on these measurements, is too high. It has therefore become necessary to mitigate the existing risk by exploring new ways of measuring mental workload.

It was decided that in the absence of a precedent or clear guidelines for a valid and reliable measurement technique, a new technique should be developed which will meet the criteria as stated in the literature. Considering the operational environment in which the results of this study may be applied, it was decided to pursue a participative and transparent development process that would allow for buy-in and high acceptance by the users of the system. These conditions were important as it will be operational managers, not mental workload specialists, who will use the tool to assist them to make operational decisions that relate to human factors and human performance.

The following were the criteria to be met by the Mental Work Load Index (MWLI) measurement method:

Construct validity was especially important because the process had to actually measure the factor *mental workload* and not another factor such as fatigue, which could be incorrectly perceived to be mental workload.

The predictive validity of the measurement technique for mental workload was also important as the mental workload measurement technique had to assess and/or predict the stress that the mental workload of a particular section could create for TCOs controlling that section.

Other criteria which it was considered important for the methodology to comply with were:

- Non-intrusiveness: TCOs perform safety-critical tasks and the method used may not distract them or affect their performance while executing their tasks.
- Operator and user acceptance.
- Sensitivity: the method should detect changes or differences in the mental workload imposed.
- Implementation requirements and affordability: the method should be easy to learn and administer, be portable and once developed, should be inexpensive to implement and maintain.

Although the primary objective of this project was the objective measurement of mental workload, there are other important aspects that had to be considered and that were related to the methodology for developing such a measure. An important envisaged benefit of the methodology is that it will be a scientifically developed process that could be defended should a legal, industrial relations or operational safety dispute arise with regard to the mental workload of TCOs in train control centres.

It must be borne in mind that the envisaged methodology is primarily aimed at determining the content of tasks and the mental workload demands these may place on operators. The mental workload should not be confused with on-the-job performance of the operators, which is a function of mental and physical workload combined with factors such as motivation, alertness, physical health and mental wellbeing.

In summary, the aim of the envisaged methodology is to create a management tool that can be applied to classify different railway lines and sections in terms of the mental workload they will impose on operators. Such classification will in turn facilitate planning and the allocation of resources to ensure safe train control practices and operations.

3.3 SUMMARY OF THE DEVELOPMENT PROCESS

The study was implemented in two phases, namely a project phase and a pilot study phase.

- The project phase commenced with a project proposal, which outlined the elements that would be addressed in the study and was based on a task analysis of TCO activities.
- The pilot study phase, which ran concurrently with the project phase, served as a feasibility study to determine whether some of the goals outlined in the proposal were attainable.

The following flow diagram outlines the development process of the mental workload index:

Table 3.1: Flow diagram of development process of the mental workload index

MWLI DESIGN PHASES	PILOT STUDY PHASES
CATEGORISE TRAIN CONTROL CENTRES IN TERMS OF PERCEIVED WORKLOAD Users of the system participated in an exercise to categorise train control centres into high, medium, and low workload based on their perception of how difficult the various centres were to operate.	
↓	
DEVELOP AND APPLY TLA An analysis of the TCO tasks was conducted and a TLA was developed for the train control environment. The TLA was applied on a representative number of centres. →	CHOOSE A HIGH AND LOW WORKLOAD CENTRE A high and low centre was chosen for use in a pilot study to test the physiological protocol to be used in the validation study.
↓	↓
SUPERIMPOSE RADIO AND TELEPHONE RECORDS ON TLA All communications between TCOs and other parties are captured on a voice logger. The record for the day and shift the TLA was done was extracted and compared with the TLA information for verification.	APPLY PHYSIOLOGY PROTOCOL TO TEST DISCRIMINATORY ABILITY OF PROTOCOL The protocol was used and the results obtained were indicative of low and high stress associated with workload.
↓	↓
WEIGH TASKS Through expert and user perception analysis, verification of the tasks was performed and weights were attributed to the various task elements, proportional to their respective contribution to mental workload.	CORRELATE MWLI WITH PHYSIOLOGY PROTOCOL The physiological protocol (identified during the pilot study) was applied on a representative sample of train control centres to correlate the stress measurements with the calculated MWLI.
↓	
DEVELOP PROVISIONAL WORKLOAD MEASUREMENT INDEX Based on the weights of the various tasks, a formula was developed which represented the mental workload index (MWLI).	
↓	
APPLY INDEX ON LOW, MEDIUM AND HIGH WORKLOAD CENTRES The index was calculated for all the train control centres to establish whether the MWLI correlated with the perceived low, medium and high centres.	

3.4 STEPS IN THE DEVELOPMENT PROCESS AND ASSOCIATED INSTRUMENTS

The above development process comprised the following steps and related instruments:

A. A list of all RTO centres was compiled. Experienced representatives from the different groups of role players (expert users of the system) were requested to categorise the train control centres (and the sections that they control) into low, medium, and high in terms of traffic density, i.e., number of trains, maintenance activities and communication. Their instruction was to categorise the list of RTO centres into high, medium and low centres in terms of their perception of how difficult these different centres are to operate.

B. An analysis of the TCOs' tasks was conducted to determine the elements that should be included in the TLA.

C. A TLA checklist was developed specifically for the train control environment (See Addendum B).

D. Concurrent with step C, a pilot study was conducted to establish the physiological test protocol to be used in the validation of the mental workload index.

E. The TLA was applied per centre, using representative shifts, in order to determine what constituted the tasks, how much time was spent on the different activities, and to compare the possible differences between the different categories of centres.

F. Radio and telephone records were obtained and superimposed on the TLA. All communications between TCOs and other parties were logged on a voice logger. The record for the specific day and shift when the TLA was done was extracted from the voice logger and compared with the data captured on the TLA. The number and duration of radio and telephone communications were of specific importance because of their impact on the total workload experienced during a shift. It was, therefore, important that this information was captured correctly, and the voice logger records were used to verify the TLA information.

G. The various factors were weighted through a process of multicriteria decision modelling and expert analysis. This complex process comprised several steps, which in summary entailed the following:

- A group of expert users of RTO confirmed the elements of the TLA.

- The tasks/factors that contributed to workload, as identified through the application of the TLA, were weighted by a panel of user experts through a process of user perception analysis. (The Visual Interactive Sensitivity Analysis [VISA] was used to facilitate this process). This process was facilitated by an experienced operational researcher, who acted as an independent facilitator.
- Scales (Likert and quantitative) were developed to measure these factors. These scales are multidimensional in nature and they had to reproduce the proportionality of the specific factor, since the different factors do not contribute to the total workload on an equal basis.

H. The provisional workload measurement index was developed.

I. The provisional method was applied on the categories of low, medium and high workload centres (as categorised by expert users) to test the discriminatory ability of the method.

J. A study was undertaken to correlate physiological measurements of stress with the MWLI. This consisted of the following steps:

- Calculate the MWLI for a particular shift at selected train control centres.
- Apply the physiological protocol (as identified during the pilot study) on TCOs at the selected train control centres to determine what workload stress the subjects experienced and to correlate this with psychophysiological data for that same period.
- Correlate stress measurements and the calculated MWLI.

3.5 DETAILED DESCRIPTION OF THE DEVELOPMENT PROCESS

3.5.1 Listing and Categorisation of Radio Train Order/Track Warrant Train Control Centres

At the inception of the project, all train control centres that used radio train orders/track, warrant had to be identified in order to determine the extent of the study.

These centres were identified by the technical expert on the project team, who also categorised the centres into groups of high, medium and low intensity, based on the traffic volumes at the time. Expert users of the radio train order system, TCOs, and their supervisors were used to verify this categorisation. The rationale behind the categorisation by users of the system was to obtain an uncontaminated response based on the experience of the TCOs. At a later stage, this rating was correlated with the actual calculated MWL index.

3.5.2 Task Analysis

A task analysis was obtained to ascertain what the different elements are that constitute TCOs' tasks, and especially what contributes to their workload.

A task analysis gives an indication of what the task elements (activities) are that TCOs perform during a shift, but does not give an indication of how much time is devoted to these different activities. It must be kept in mind that the availability, or non-availability, of time, to perform work is the major component of mental workload and stress in the work context.

A task analysis, by means of task observation of the train control centre at the ZASM Building, Pretoria, was undertaken. These TCOs control the Rustenburg/Thabazimbi line. The following tasks were identified upon analysis of the information obtained:

- planning shift activities
- establishing which trains are scheduled for the shift
- plotting train movements on train schedule sheets
- controlling train movements by:
    - communicating by radio with train drivers
    - monitoring conversations of maintenance teams and other users of the track on the section on radio(s)
    - receiving requests for authorisations from train drivers by radio
    - planning the train movement on the train diagram
    - comparing the information on kilometre points on the section (on a different

database) with planned movement to verify safety of the movement
    - completing the train order by referring to the train diagram in order to determine other train movements, establishing whether it is safe for the train to proceed to the next point, and obtaining an authorisation number from the records
    - writing the authorisation number, train number and train-driver details on a separate sheet
    - communicating the authorisation number to the train driver and waiting for confirmation from the train driver of the number
    - plotting train movement that have been authorised on the train diagram
- answering telephone calls from locomotive depot staff, maintenance staff or commercial personnel on train movements
- writing up reports regarding activities en route, such as locomotive failures, maintenance activities, shunting activities
- capturing incidents (locomotive failures or infrastructure problems, such as broken rails and criminal activity) and information on estimated times of arrival (ETAs) and estimated times of departure (ETDs) by accessing the data system on computers designed for capturing this data
- performing personal activities during discretionary time (making coffee, going to bathroom, reading)

In order of importance, the following are the priority tasks that are performed by TCOs:
- planning and authorisation of a train movement
- communicating the authorisation to the train driver
- ensuring that the authorisation was received correctly by the train driver
- keeping track of other activities, responding to unplanned events on the section, and communicating with the relevant parties

Devoe (1974) identified six functions that appeared to cover all the tasks of a dispatcher:
- prepare documentation
- conduct preliminary planning
- monitor/coordinate train movements

- initiate/stop train movements
- respond to unplanned events
- respond to emergencies

Of these, the functions of planning and decision making were considered the most critical.

Popkin et al. (2001) identified the following dispatcher tasks:

- planning
- controlling track use
- managing unplanned and emergency events
- record keeping and report writing

A comparison of the three sets of activities (Devoe, 1974, Popkin et al., 2001, and the Spoornet TCO tasks) shows significant congruency in terms of the planning and controlling/monitoring of train movements and responding to unplanned events, which, together with communication, appear to be the most critical tasks.

It is interesting that Popkin et al. (2001) note that as much as 75% of the dispatchers' shift may be spent communicating on the radio or telephone. This leaves little time for accomplishing other duties. Conversations with TCOs during development of the MWLI and during data collection indicated that sources of stress were related to telephone calls that caused them to divert their attention from train movements to other matters such as permanent way maintenance, requests related to the ETA/ETD of trains and general enquiries, as well as personal calls.

While performing the task observation it became evident that these tasks are often executed concurrently, such as receiving a request to authorise a movement while planning another movement or receiving a phone call while communicating an authorisation over the radio.

Once it was established which tasks occupied TCOs, it was necessary to determine how much time was spent on each activity. The Timeline Analysis was well suited for this purpose.

3.5.3 Timeline Analysis

A common approach to absolute workload and performance prediction is Timeline Analysis (TLA), which enables the system designer to 'profile' the workload that operators encounter during a typical mission, such as landing an aircraft or starting up a power-generating plant.

TLA is a process of systematically analysing how much time is devoted to which activities over a given period of time. It examines the temporal relationships among tasks and the duration of the tasks (Meister, 1985). As stated before, the time pressure factor is an important aspect in the total process of mental workload assessment. Timeline analyses are not only useful in determining workload but are also important functional breakdown techniques that can determine what the different elements of the task are and the time distribution over these elements. TLA allows observers to determine how much time is devoted to particular activities over a period of time, e.g., a shift.

The TLA technique provides for an objective mechanistic breakdown of the demands made upon operators in terms of time. It cannot measure the actual load placed on operators and therefore could not be used as a stand-alone method in the assessment of mental workload. The TLA is important in mental workload analysis for a number of reasons, e.g.:

- It forces analysts to break a job down into all its different tasks and activities.
- It gives an indication of how much time is devoted to a particular activity/task.
- It gives an indication of how much time in total has been taken up during a certain period of work.
- The most important value of a TLA is that it gives an indication of tasks that simultaneously lay claim to the attention of the operators.

It is these simultaneous demands on the attention of the TCOs that contribute substantially to the TCOs' workload and that could result in stress and contribute to judgement errors. TLA is critical in workload analysis, since the time factor is an important aspect in the process of mental workload assessment.

A TLA technique that was used effectively in the dispatching environment is a modified version of the Task Analysis Workload Measure (TAWL) by Popkin et al., (2001). The TAWL, developed for the assessment of military helicopter flight crews, was modified to suit the dispatching operational environment and is referred to as the mTAWL.

The mTAWL is a task-oriented approach that assumes that dispatchers perform multiple, simultaneous tasks through time, and that these individual tasks may vary in their demand on the dispatchers' performance resources. The mTAWL treats workload as the sum of the difficulty of all concurrent tasks for each minute of an observation. Two dispatchers may handle an equal number of trains, yet significant differences may exist in workload across a shift if one of the dispatcher's activities takes place within a short period of time while the other dispatcher's load is spread evenly over time. The mTAWL is sensitive to this difference. The mTAWL also takes the difficulty of a task into account. Two tasks may be of equal time duration, yet one task may call on more resources of listening, watching, thinking or overtly acting than the other. The mTAWL refers to these resources as auditory, visual, cognitive or psychomotor channels. The mTAWL method calculates workload by adding the loads for each of the individual channels across all tasks for each minute of a dispatcher's shift.

A TLA format was used in this study during the first phase of the MWLI development (see Appendix B). The purpose was to record the activities of TCOs at particular train control centres. An eight-hour shift was divided into 15-minute sections and the activities performed (often concurrently) were captured per 15-minute periods. The tasks identified using the task analysis and TLA were further analysed and were eventually included in the Mental Workload Index.

3.5.4 Pilot Study

The purpose of the pilot study was to develop and to evaluate the proposed physiological protocols and data collection procedures, and to determine whether the selected protocols would discriminate between high and low mental workload. The Department of Medical Physiology, University of Pretoria, assisted in determining which measures would be practicable in the specific circumstances for the selected protocol. The research was conducted *in situ*, in the TCOs' workplace. The assurance that the data collection would not interfere with the TCOs' ability to perform their job was a major consideration in the design of the study. In order to satisfy the requirements of the Ethics Committee of the University of Pretoria and to ensure objectivity and consistency in the data collection process, staff members of the Medical Physiology department were responsible for performing the physiological measurements.

With the assistance of the team of physiologists a protocol to measure allostatic load associated with mental workload was developed. The protocol for allostatic load consists of 13 measurements, most of which are measured in blood (such as total cholesterol, adrenalin and noradrenalin). The collection of blood samples was not considered feasible for this study due to its intrusive nature. The parameters included in this study were:

- Blood pressure – diastolic (DBP) and systolic (SBP) blood pressure were measured with a digital electronic blood pressure meter (ALP K2, model DS-125D, Japan).
- Heart rate – measured with Polar heart rate monitors (Polar Electro).
- Cortisol – free salivary cortisol was determined with a Salivary Cortisol ELISA kit (SLV-2930, DRG Instruments GmbH, Frauenbergstrasse, Marburg, Germany).
- The Body Mass Index (BMI) was also calculated as it provides an indication of the metabolic effects of stress.
- TLA.
- Cohen's Perceived Stress Questionnaire.

Permission was obtained from the Ethics Committee of the University of Pretoria for the physiologists at the Department of Medical Physiology to use these protocols, and a pilot study was performed at the Welgedag train control centre during June 2001. The reasons for choosing the Welgedag train control centre were twofold:

- This specific train control centre controls more than one section; the one section was rated as high and the other as low in terms of traffic density and therefore perceived workload.
- Geographically the centre was within reasonable travelling distance from Pretoria should repeat visits become necessary.

The results were conclusive and indicated that the measurements were sensitive enough to distinguish between high and low workloads (see Appendix C for the Pilot study report).

The following problems were, however, encountered:

- Electromagnetic interference was experienced in the train control centre, which affected the reliability of the Polar heart rate monitor (a chest strap which transmits a radio signal to a wrist receiver). It was recommended that a different type of monitor be used that makes use of a direct cable connection rather than the radio transmission of a signal.
- Because it was subsequently established through a literature review that most of the research indicated that heart-rate variability is a more sensitive measure of the stress associated with mental workload, and since a new instrument, in any event, needed to be sourced to replace the Polar heart rate monitor, it was decided to measure heart-rate variability (HRV) rather than heart rate. Using heart-rate variability would put this study on an equal footing with international studies and would make comparative analysis easier.

3.5.5 Application of the Timeline Analysis (TLA)

Using representative shifts, the TLA checklist was applied to a number of train control centres. The aim was to determine whether the activities in all train control centres were the same, and to develop a better understanding of the time spent on each activity (which could give an indication of the complexity of the specific activity). This was necessary when developing the index and when assigning weights to different activities. The TLA was also used to compare high- and low-traffic-density centres with one another.

3.5.6 Radio and Telephone Records

Radio and telephone records for all the identified centres were obtained and superimposed on the TLA. In other words, this information was added to the TLA information to provide a clearer picture of the tasks and the time spent on them.

3.6 DEVELOPMENT OF THE MENTAL WORKLOAD INDEX

Considering the wealth of information on mental workload assessment that has accumulated over the last three decades, the question, "Why a new methodology?" can legitimately be posed.

The need was identified for a fit-for-purpose and easy-to-use means of assessing and predicting the potential workload that could potentially be experienced at train control centres. The MWLI does not claim to replace or to be superior to any of the existing assessment tools, especially as it does not measure the actual workload that can be experienced by TCOs at any specific point in time. It is based on task-load factors and on a number of mediating factors. It is aimed at providing rail operations managers with a means of identifying and highlighting potential problem train control centres, without their needing specialised assistance to do so. The MWLI could be calculated as a desk-top exercise because it uses objectively collected information that can be obtained from a central database. It does not necessitate an on-site review of the activities at a specific train control centre. The tool is also useful in developing different scenarios by changing the values of the factors and then predicting what the workload will be. The value of this is that workload estimates could be determined before changes to train control systems or personnel are made.

An important consideration in the development of a tool to be used in the train control environment was that of intrusiveness. As discussed in an earlier section, intrusiveness refers to the tendency of a measurement technique to cause unintended degradations in ongoing primary-task performance. This can pose potentially serious problems in the application of a workload measurement technique. Such problems are primarily related to the interpretation of results obtained with an assessment procedure, and with the application of techniques to operational environments. Levels of intrusiveness that may be acceptable in the laboratory might not be tolerable in operational environments where any compromise in system safety would be unacceptable.

Many of the measurement procedures that have been developed are very promising, but they are still largely restricted to research environments. It appears equally clear that because of the complexity of the workload construct, it is unlikely that any single measure will be completely adequate in providing the type of applied measurement mechanism that is desired, and at the same time be applicable to all kinds of applied work situations (Reid and Nygren, 1988).

The Mental Workload Index was developed over a number of iterations and after several group sessions. The group sessions comprised the same group of people every time, and were facilitated by an independent operational researcher. The group represented all potential stakeholders namely technical experts, users of the radio train order system (TCOs) and their supervisors, as well as trade union representatives. The result was an evolutionary developmental process of the mental workload index.

The outcome of the iterative process was consensus and acceptance of the following factors to be included in the MWLI (See summary in Table 3.2):

- Three task elements (additive), descriptive of the content of work – the sum of the elements makes up the *quantity* of work. The three selected task elements are the number of data transactions, the number of authorisations, and the number of communications via telephone and radio.
- Eleven moderating factors (multiplicative), descriptive of the *nature* of the work – the moderators influence the complexity of the work, irrespective of the quantity, e.g., the type of shift and the experience of the TCOs.

The proposed model was initially of the form:

$$I = \sum_{i=1}^{3} T_i * \prod_{j=1}^{11} M_j$$

MWLI = (sum of task elements) × (product of moderating factors) or
where I is the MWLI in arbitrary units, T_i, i=1,2,3 are the three task elements, and M_j, j=1, 2,…,11 are the maximum values of the eleven moderating factors.

Due to the difference in the relative importance of each task element and moderating factor to the overall mental workload, both the task elements and the moderators were weighted.

The weighting factors for each were also determined by the work group. The MWLI was refined as follows:

MWLI = (sum of weighted task elements) × (product of weighted moderating factors) or

$$I = \sum_{i=1}^{3} T_i * W_i * \prod_{j=1}^{11} M_j * V_j,$$

where I is the MWLI, W_i, are the weights of the three task elements T_i, i.e., i=1,2,3, and V_j, are the weights of the eleven moderating factors M_j, with j=1, 2,…,11, and $\sum$,$\prod$ designate sum and product over the indicated terms.

Table 3.2: Elements of the MWLI

Task Elements		Moderators		
Item no.	**Description**	**Item no.**	**Description**	**Maximum Weight (%)**
1	Number of data transactions	1	Shift	12
		2	Experience	18
2	Number of authorisations	3	Interface complexity	5
		4	Running times	8
3	Number of communications via telephone/radio	5	Crossing places	6
		6	Platform location	3
		7	Trains vs. number of crossing places	11
		8	Type and mix of trains	9
		9	Locomotive depots	10
		10	Shunting activities	14
		11	Topography	4

The range of the MWLI is from 0 to NN, where the minimum corresponds to zero transactions, authorisations and communications, and the maximum NN corresponds to the peak number of transactions, authorisations and communications, with the worst case for each of the moderators. In practice the MWLI ranged from 89 to 5789 for the 36 train control centres that were part of the study.

3.7 IDENTIFICATION OF TASK AND MODERATING FACTORS

An initial task analysis of the activities performed by TCOs during a shift was performed in order to identify the tasks. During a TLA the activities and number of times they are performed, per operator, are captured every 15 minutes. Several activities directly related to the task were identified. The project team, together with expert users of the system, analysed the data obtained from the TLAs.

The following iterations were performed in order to reach final consensus and acceptance of the factors to be included in the MWL Index.

Table 3.3 Iterative process in the development of the mental workload index

	Task Elements	Moderators
First Iteration	• No. of authorisations (no. of trains × no. of radio authorisations per train) • Weighted no. of authorisations (no. of authorisations × authorisation weight – weight as yet undetermined – arbitrary figures used to illustrate concept) • Total no. of actions (weighted no. of authorisations + no. of telephone calls)	• Difficulty of the section • Shift type • Tiredness • Error impact • Experience (Moderators as yet unquantified – arbitrary figures used to illustrate concept)
	MWL Index = Sum of actions (weighted) × Product of moderators	
Second Iteration	• No. of data transactions • Weighted no. of data transactions (no. of data transactions × data transaction weight – weight as yet undetermined - arbitrary figures used to illustrate concept) • No. of radio authorisations • Weighted no. of authorisations (no. of radio authorisations × authorisation weight – weight as yet undetermined – arbitrary figures used to illustrate concept) • No. of telephone/radio communications • Weighted no. of actions (weighted no. of data transactions + weighted no. of authorisations + no. of telephone/radio communications)	• Inherent difficulty of the section • Scheduling complexity • Interfacing difficulty • Type/mix of trains • Type of shift (fatigue) • Duration of shift • Experience (Moderators as yet

	Task Elements	Moderators
		unquantified – arbitrary figures used to illustrate concept)
	MWL index = sum of actions (weighted) × product of moderators	
Third Iteration	• No. of data transactions • No. of authorisations • Weighted no. of authorisations (no. of authorisations × authorisation weight) – authorisation weight = 15 (see discussion below) • No. of other telephone/radio communications • Weighted no. of communications (no. of other telephone/radio communications × telephone/radio communications weight) – telephone/radio communications weight = 5 (see discussion in paragraph 4.4.1) • Weighted no. of actions (no. of data transactions + weighted no. of authorisations + weighted no. of communications)	• Inherent difficulty of the section • Planning complexity • Interface complexity • Type/mix of trains • Type of shift (fatigue) • Duration of shift • Experience (Moderators as yet unquantified - arbitrary figures used to illustrate concept)
	MWL index = sum of actions (weighted) × product of moderators	
Fourth Iteration	• No. of data transactions • No. of authorisations • Weighted no. of authorisations (no. of authorisations × authorisation weight) – authorisation weight = 15 (see discussion in paragraph 4.3.1) • No. of other telephone/radio communications • Weighted no. of communications (no. of other telephone/radio communications × telephone/radio communications weight) – telephone/radio communications weight = 5 (see discussion in paragraph 4.4.1) • Weighted no. of actions (no. of data transactions + weighted no. of authorisations + weighted no. of communications)	• Shift (weight: 12%) • Experience (weight: 18%) • Interface complexity (weight: 5%) • Running times (weight: 8%) • Crossing places (weight: 6%) • Platform location (weight: 3%) • Trains vs. crossings (weight: 11%) • Type & mix of

	Task Elements	Moderators
		trains (weight: 9%) • Loco depots (weight: 10%) • Shunting (weight: 14%) • Topography (weight: 4%) (Discussion of weight allocation in paragraph 4.4.2)
	Workload index = total no. of actions (weighted) × product of moderators (weighted)	

The process of identifying task elements and moderators and determining the weight of each spanned a period of eight months.

3.8 DEFINITION OF TASK AND MODERATING FACTORS

3.8.1 Definition of Final Task Elements

3.8.1.1 Number of data transactions

This factor includes data that TCOs have to capture over and above the data required for an authorisation. Data transactions that are typically executed are Spoornet Information Management System (SIMS), estimated time of arrival (ETA), and estimated time of departure (ETD) entries. Data included in the calculation of the Mental Workload Index represents the capturing of SIMS and ETA/ETD data. No other data is captured by TCOs. Some train control centres do not capture any data transactions. This is indicated by a 0 (zero) on the table. The total number of data transactions is calculated by adding the number of SIMS and ETA/ETD transactions executed.

The rationale for including this factor was that any activity that would increase the workload of TCOs had to be included in the index. This activity increases the time demands on TCOs and requires accuracy and therefore concentration.

The number of data transactions is captured on a central database for SIMS and the information was extracted directly from that database.

3.8.1.2 Number of Authorisations

This factor represents the essence of the output of TCOs. Adding the number of authorisations for the purposes of calculating the mental workload index is a simple exercise and belies the complexity of executing the task.

The issuing of an authorisation for a train to proceed to a point further in the section entails the following actions:

- The TCOs have to consult the train diagram. The train diagram contains the planned train movements for the shift as well as the actual train movements. Planning is done by the TCOs at the start of the shift and actual movements are updated as trains move through the section. This type of train control does not have a panel that shows the movement of trains in the section. The TCOs have only a hand-drawn train diagram (computer-based if TWS is used in conjunction with RTO) that shows train movements and where trains will cross.
- Trains crossing each other in the section require careful planning as this type of train control occurs on a single track, and crossings can only be done at stations or loops in the section.
- Before a train can be authorised to proceed to a predetermined point, the TCOs need to ensure that traffic from the opposite direction is on time as indicated by the train diagram. If not, alternative plans have to be made, such as using an alternative crossing place or keeping a train (in most instances the train that is behind schedule) back. The train diagram has to be adjusted to reflect this change.
- All authorisations occur via radio communication. The train driver contacts the TCO on the radio when the point up to where authorisation was received has been reached. The TCO then executes the above-mentioned activities before authorising the train driver to proceed. The TCO radios the train driver when the planning for the movement has been completed. The train driver performs identity verification by providing the train number as well as the kilometre point where the train is waiting. The TCO

confirms this information over the radio while writing it down on an authorisation sheet. An authorisation number is given to the train driver which is in turn confirmed by the train driver.

- The train then departs from the waiting point. The TCO updates all the information on the train diagram and proceeds to plan for this particular train movement, i.e., when the train will reach the next point according to train running times, which are predetermined. In this study it was found that anything between 1 and 97 authorisations could be issued during an eight-hour shift.

The complexity of this element is captured in the moderating factors as well as in the weight assigned to this task (see explanation below of how weights were assigned).

The number of authorisations was obtained from the manual records kept by the TCOs.

3.8.1.3 Number of Telephone/Radio Communications

Communication via radio or telephone is an integral part of the job function of TCOs. All authorisations are communicated via radio or telephone. These are not the only communications TCOs deal with, and a variety of other requests and queries are also channelled through them, such as the activities of maintenance teams, information on ETA and ETD, information on breakdowns or locomotive failures, and shunting activities.

The information for this element was obtained from the voice logger, which records the communications of the TCOs during their shift. The number of communications was calculated by adding the individual communications captured on the recording system.

3.8.2 Definition of Final Moderators

It would of course be meaningless to attempt quantification of the moderators if all members of the work group did not use the same definitions. The definitions for the earlier versions of the model have not been included in this document. The final set of moderators was defined as follows:

3.8.2.1 Shift

Time of day and length of shift.

All possible shifts that are normally worked were captured in the scale, but it might happen that, due to special circumstances, such as people being on sick leave, TCOs would work a longer shift that does not fully correspond with the options provided. The option on the scale with the greatest overlap with the actual shift time will then be selected.

3.8.2.2 Experience

Level of applicable experience expressed in number of years.

Applicable means experience in the specific train control system under evaluation. Relevance of experience is reduced by interrupted service.

3.8.2.3 Interface complexity

Interface with other train control systems such as colour light signalling.

Interfaces can be single or multi-interface, meaning that in one direction of the section there could be an interface with colour light signals and in the other direction there could be semaphore signalling. TCOs have to take cognisance of these interfaces when communicating with train drivers.

3.8.2.4 Running times

Running times of trains in a specific section within limited variations. Running times are pre-established and are contained in rule books.

3.8.2.5 Crossing places

Types of points sets, e.g., hand points, electrical points or self-normalising points.

Critical gradients on approach to a crossing place and level crossings within a train length, from the facing points, are also important factors to consider.

3.8.2.6 Platform location

The presence or absence of platforms in the section.

This complicates the planning tasks of the TCOs. For example, if a passenger train is brought into a station that is simultaneously used as a crossing place with another train, and passengers need to embark or disembark, the train must be taken into the station on the side where the platform is located.

3.8.2.7 Number of trains vs. number of crossing places

The impact of the relationship between the number of trains versus the number of crossing places can have considerable impact on planning complexity. The correlation between the two variables is not linear.

3.8.2.8 Type and mix of trains

The presence of various types of trains with varying priorities.

Different trains carry different priorities. The Blue Train (a luxury passenger train) has the highest priority and always gets preference if one train has to wait for another at a crossing place. Name trains, such as the Trans Karoo, Diamond Express or Trans Natal have second priority. Hazardous materials trains, such as those that transport explosives or petrochemical products have third priority. Block trains, which are assigned to a specific client such as Sappi, have fourth priority. Other passenger and goods trains follow further down on the priority list. TCOs need to know which types of train run on their sections in order to plan properly.

3.8.2.9 Locomotive depots

The presence or absence of locomotive depots en route.

The presence of locomotive depots results in more train movements due to locomotives being shunted to couple or uncouple loads.

3.8.2.10 Shunting

The presence of shunting activities in the section.

3.8.2.11 Topography

The nature of the terrain and landscape through which the section runs.

Scales to describe these factors were developed. These scales are multidimensional and they reproduce the proportionality of the specific factor, since the different factors do not contribute to the total workload on an equivalent basis (Table 3.4).

Table 3.4: Definitions of moderators

Moderator	Definition	Scale	Range
Shift	Time of day and length of shift	8-hour time periods over a 24-hour period	1-5
Experience	Level of applicable experience expressed in number of years (*Applicable* means experience in the specific train control system under evaluation. Relevance of experience is reduced by interrupted service.)	Expressed in number of years	1-4
Interface complexity	Interface with other train control systems	Same system or different system; single- or multi-interface	1-4
Running times	Running times of trains in a specific section within limited variations	Uniform or varying running times (dependent on type of trains)	1-4
Crossing	Types of points sets, e.g., hand points,	Uniform or	1-2

places	electrical points, self-normalising points, etc. Also critical gradients on approach to crossing places and level crossings within a train length from the facing points	varying	
Platform location	The presence or absence of platforms in the section. This complicates the planning tasks of TCOs	Presence and position of platforms	1-4
Number of authorisations vs. number of crossing places	The impact on planning complexity of the relationship between number of authorisations vs. number of places where trains can cross	Low to very high impact – expressed in matrix	1-4
Type and mix of trains	The presence of various types of trains with varying priorities	Types of trains and variation	1-4
Locomotive depots	The presence or absence of locomotive depots en route	Presence and number and depots	1-4
Presence of shunting yards/ activities	The presence of shunting activities in the section	Presence of shunting yards, private sidings	1-4
Topography	The nature of the terrain and landscape through which the section runs	Flat through hilly; urban through city	1-4

3.9 ALLOCATION OF WEIGHTS AND QUANTIFICATION OF MODERATORS

3.9.1 Authorisation and Communication Weights

During a facilitated work session using a modified nominal group technique with the work group, the participants came to the conclusion that capturing data transactions was the simplest of the tasks carried out by TCOs.

The modified nominal group technique process was facilitated by an independent operational researcher and entailed eliciting ideas from participants, in this case their ideas about the essential tasks of TCOs. The aim was to facilitate open participation, where everyone's ideas had equal importance, irrespective of their position or status. Ideas were written on post-it™ paper notes (one idea per note) and stuck on a blackboard. With the assistance of the facilitator, ideas with the same meaning were grouped together and the idea was then classified in terms of importance. Using their perceptions of the work content of a data transaction as a basis, the work group reached consensus that an authorisation transaction entailed fifteen times as much work (in terms of content and complexity) as a data transaction. Similarly a telephone or radio communication on average entailed five times as much work as a data transaction. Hence the weights used in the model:

Data transaction	: 1
Authorisation	: 15
Telephone/radio communication	: 5

3.9.2 Moderator Weights

Once again, during a series of sessions and using the modified nominal group technique, the work group decided that *platform location* was the least taxing of the moderating factors.

Experience of the operator was considered to be the factor that contributed most to the mental workload, and group consensus was that experience should carry six times the weight of *platform location*. The other moderating factors were then placed in order of diminishing importance between *experience* and *platform location*, and a simple geometric representation was used to assist the group in reaching a consensus on the relative contribution of each moderator.

The resulting values were then normalised (scaled so that they added up to 100%), resulting in the weights appearing in the Mental Workload Index.

3.9.3 Scale Points of Moderators

A similar logic to that used to allocate weights to the moderators was employed to determine scale points for the moderators.

Consider, for example, the moderator *shift type*. The work group first defined scale points 1 to 5. They then reached consensus that scale point 1 (i.e., the 06:00 to 14:00 shift) was the least taxing, and a value of 1.0 was allocated to this point (multiplication by 1.0 leaves the index unchanged, i.e., there is no moderation). Next, consensus was reached that scale point 5 (i.e., the 18:00 to 06:00 shift) was the most taxing, and it was allocated an arbitrary rating greater than 1. The decision of the work group relating to the most and least taxing shifts was verified with human factors and stress experts. It was confirmed that in terms of physiological factors (circadian rhythm, drowsiness, and mental alertness) the 18:00 to 06:00 shift was the most difficult and the 06:00 to 14:00 shift was the easiest. The other scale points were then allocated ratings between 1.0 and this maximum value. The intermediate ratings were debated and adjusted until the group agreed that the differences in allocated ratings were in the proper relation to their assessments of the differences in mental workload.

Another example is the factor *experience as a TCO on the particular system.* The work group identified four phases in the career of TCOs that could moderate experienced workload:

Table 3.5: Example of scale point development

Scale	Factor	Rationale
Up to 2 years after being licensed	2	Too little experience to effectively cope with difficulties and demands. Highest moderating impact.
2 to 7 years after being licensed	1	Suitably experienced to cope with problems, find solutions and remain in control. Remains vigilant and alert. No moderating effect.
7 to 12 years after being licensed	0.8	Experienced, has developed an intuitive approach to the demands – 'knows' when problems are likely to occur. Makes load easier.
More than 12 years after being licensed	1.2	Becomes complacent – not sufficiently alert and vigilant. Moderates workload – will increase workload

The allocated factors were based on the experience the work group had had in their own careers and with their subordinates, whom they manage daily.

Other scale points of the moderators were similarly determined to be the most or least taxing. In all the other instances, the expertise and experience of the work group and a consensus decision determined the scale point values.

Finally, when the same procedure had been repeated for all the moderators, all the ratings were mathematically scaled in such a way that the highest moderating value in each case corresponded to the weight allocated to the moderator. For example, the maximum moderating factor for *shift worked* (weight 12%) is 1.12 (the maximum moderating effect was achieved by multiplying by 1.12 which means that the index value was moderated by 12%). The same logic was applied to all the moderators resulting in the descriptions reflected in the table below:

Table 3.6: Description and weights of moderating factors

1. SHIFT TYPE

1.1 Shift Worked (Weight: 12%)

- Time of day and length of shift
- Select the time period with the greatest overlap with the actual shift time

Factor	Scale Pt	Description
1.00	1	06:00 – 14:00
1.04	2	14:00 – 22:00
1.12	3	22:00 – 06:00
1.10	4	06:00 – 18:00
1.15	5	18:00 – 06:00

2. EXPERIENCE AS A TCO ON THE PARTICULAR SYSTEM

2.1 Experience in Years on RTO/TWS (Weight: 18%)

- Level of applicable experience expressed in number of years
- *Applicable* means experience in the specific train control system under evaluation
- Relevance of experience is reduced by interrupted service

Factor	Scale Pt.	Description
2	1	Up to 2 yrs after being licensed
1	2	2 to 7 yrs after being licensed
0,8	3	7 to 12 yrs after being licensed
1,2	4	More than 12 yrs after being licensed

3. **PLANNING COMPLEXITY** (Total Weight: 30%)

3.1 Interface Complexity (Weight: 5%)

- Interface with other train control systems (single or multi-interface)

Factor	Scale Pt.	Description
1	1	Single interface, system to system
1,2	2	Multi-interface, system to system
1,4	3	Single interface, with another system
1,6	4	Multi-interface, with another system

3.2 Running Times between Crossing Places (Weight: 8%)

- Running times of trains in a specific section within limited variations

Factor	Scale Pt	Description
1	1	Uniform running times, long (>30 minutes) (Variations <30%)
1,8	2	Uniform running times, short (<30 minutes) (Variations <30%)
1,3	3	Varying running times, long (>30 minutes) (Variations >30%)
1,6	4	Varying running times, short (>30 minutes) (Variations >30%)

3.3 Types of Crossing Places (Weight: 6%)

- Types of points sets, e.g., hand points, electrical points, and self-normalising points. Also critical gradients on approaches to crossing places and level crossings within a train length from the facing points

Factor	Scale Pt	Description
1	1	Uniform crossing places (same types of points, etc.) (Variations <30%)
1,5	2	Varying crossing places (different types of points, etc.) (Variations >30%)

3.4 Location of Platforms (Weight: 3%)

Factor	Scale Pt	Description
1	1	No Platforms
1	2	All platforms on both lines
1,2	3	Less than 50% of crossing places have platforms on one line only
1,5	4	More than 50% of crossing places have platforms on one line only

3.5 Number of Authorisations per Shift vs. Number of Crossing Places (Weight: 11%)

- Impact of relationship of authorisations vs. crossings places on planning complexity (See Matrix – Figure 6.1)

Factor	Scale Pt	Description
1	1	Low impact according to matrix
1,2	2	Medium impact according to matrix
1,4	3	High impact according to matrix
1,5	4	Very high impact according to matrix

4. <u>INHERENT DIFFICULTY OF THE SECTION</u> (Total Weight: 40%)

4.1 <u>Type/Mix of Trains</u> (Weight: 9%)

- The presence of various types of trains with varying priorities

Factor	Scale Pt.	Description
1	1	One type of train (e.g. goods train) with similar priority
1,05	2	One type of train with varying priority (e.g. goods trains – hazmat/other materials)
1,15	3	More than one type of train with varying priority (e.g. goods trains, passenger trains – excluding Metro trains, hazmat train)
1,30	4	More than one type of train with varying priority (e.g. goods trains, passenger trains – including Metro trains, hazmat train)

4.2 <u>Presence of Locomotive Depots</u> (Weight: 10%)

- The presence or absence of locomotive depots en route

Factor	Scale Pt	Description
1	1	No locomotive depot
1,1	2	One locomotive depot (at start or end)
1,15	3	Locomotive depot at start and end
1,2	4	More than two locomotive depots (including depot(s) en route)

4.3 <u>Presence of Shunting Yards/Activities</u> (Weight: 14%)

Factor	Scale Pt	Description
1	1	No shunting en route or if shunting yard or private siding is at end or start of section
1,05	2	Shunting yards en route
1,25	3	Private sidings and/or shunting activities en route
1,30	4	Private sidings and/or shunting activities plus shunting yards en route

4.4 <u>Topography</u> (Weight: 4%)

- The nature of the terrain and landscape through which the section runs
  (The impact of the presence of tunnels was considered but the applicable operating principles have no significant impact on TCOs and it was therefore not considered relevant for the index)

Factor	Scale Pt.	Description
1	1	Karoo landscape; small towns few and far between
1,05	2	Flat terrain; high-density built-up environment
1,1	3	Hilly terrain; small towns few and far between
1,2	4	Hilly terrain; high-density built-up environment

Table 3.7, below, summarises the moderating factors in terms of their scale points, moderating weight and the moderating factor used in the calculation of the MWLI.

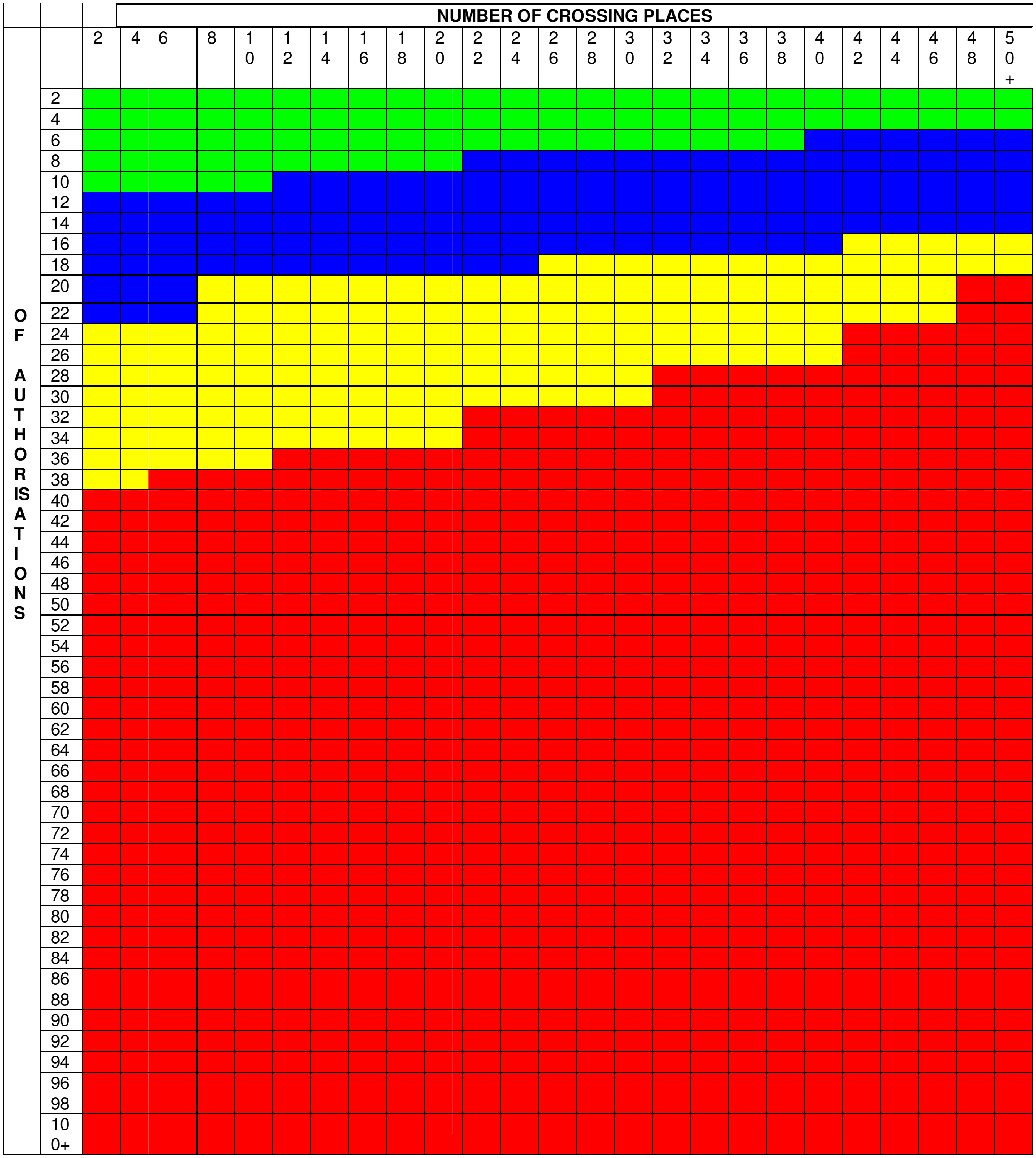
TABLE 3.7: Moderators – description of scale points and associated moderating factors

Moderator	Moderating weight	Scale Point	Description	Factor	Moderating factor
Shift worked	0.12	1	0600 – 1400	1	1.000
		2	1400 - 2200	1.04	1.032
		3	2200 - 0600	1.12	1.096
		4	0600 - 1800	1.1	1.080
		5	1800 - 0600	1.15	1.120
Experience in years on RTO/TWS	0.18	1	Up to 2 yrs after being licensed	2.5	1.180
		2	2 to 7 yrs after being licensed	1.25	1.030
		3	7 to 12 yrs after being licensed	1	1.000
		4	More than 12 yrs after being licensed	1.5	1.060
Interface complexity	0.05	1	Single interface, system to system	1	1.000
		2	Multi-interface, system to system	1.2	1.017
		3	Single interface, with another system	1.4	1.033
		4	Multi-interface, with another system	1.6	1.050
Running times between crossing places	0.08	1	Uniform running times, long (>30 minutes) (Variations <30%)	1	1.000
		2	Uniform running times, short (<30 minutes) (Variations <30%)	1.8	1.080
		3	Varying running times, long (>30 minutes) (Variations >30%)	1.3	1.030
		4	Varying running times, short (>30 minutes) (Variations >30%)	1.6	1.060
Types of crossing places	0.06	1	Uniform crossing places (same types of points, etc.) (Variations <30%)	1	1.000
		2	Varying crossing places (different types of points, etc.) (Variations >30%)	1.5	1.060
Location of platforms	0.03	1	No Platforms	1	1.000
		2	All platforms on both lines	1	1.000
		3	Less than 50% of crossing places have platforms on one line only	1.2	1.012
		4	More than 50% of crossing places have platforms on one line only	1.5	1.030

Moderator	Moderating weight	Scale Point	Description	Factor	Moderating factor
Number of authorisations per shift vs. number of crossing places	0.11	1	Low impact according to matrix	1	1.000
		2	Medium impact according to matrix	1.2	1.044
		3	High impact according to matrix	1.4	1.088
		4	Very high impact according to matrix	1.5	1.110
Type/mix of trains	0.09	1	One type of train (e.g. goods train) with similar priority	1	1.000
		2	One type of train with varying priority (e.g. goods trains – hazmat/other materials)	1.05	1.015
		3	More than one type of train with varying priority (e.g. goods trains, passenger trains – excluding Metro trains, hazmat train)	1.15	1.045
		4	More than one type of train with varying priority (e.g. goods trains, passenger trains – including Metro trains, hazmat train)	1.3	1.090
Presence of locomotive depots	0.1	1	No locomotive depot	1	1.000
		2	One locomotive depot (at start or end)	1.1	1.050
		3	Locomotive depot at start and end	1.15	1.075
		4	More than two locomotive depots (including depot(s) en route)	1.2	1.100
Presence of shunting yards/ activities	0.14	1	No shunting en route or if shunting yard or private siding is at end or start of section.	1	1.000
		2	Shunting yards en route	1.05	1.023
		3	Private sidings and/or shunting activities en route	1.25	1.117
		4	Private sidings and/or shunting activities plus shunting yards en route	1.3	1.140
Topography	0.04	1	Karoo landscape; small towns few and far between	1	1.000
		2	Flat terrain; high-density built-up environment	1.05	1.010
		3	Hilly terrain; small towns few and far between	1.1	1.020
		4	Hilly terrain; high-density built-up environment	1.2	1.040

A special procedure had to be adopted to describe the scale points for the moderator, namely "Number of authorisations per shift vs. the number of crossing places". A work group of experienced TCOs drew up a matrix by considering a wide range of combinations of the number of crossings controlled by a particular centre and the number of authorisations required per shift (See Table 3.8). The legend at the bottom of the figure enables the user to allocate any combination of the two variables to a scale point. These scale points were then quantified using the same procedure as before.

Table 3.8: Impact of number of authorisations and crossing places on planning complexity



LEGEND:

COLOUR	IMPACT ON PLANNING COMPLEXITY	SCALE POINT
Green	Very Low	1
Blue	Low	2
Yellow	Medium	3
Red	High	4

3.10 CALCULATION OF THE MWLI

Using the formula and the weights for the task and moderating factors, the MWLI was calculated for all the train control centres where RTO was being used.

The information on the contributing factors as well as the MWLI calculated for all the centres included in the validation study are shown in Figure 6.2.

3.11 CONCLUDING COMMENTS

In conclusion, a distinction between taskload and workload has been made in the literature and the rationale for considering the MWLI a workload index and not a taskload index, is as follows:

- The distinction between taskload and workload is a very fine one and not many references, where the two concepts are distinguished, could be found. Reinach (2001) differentiates between the two in the following manner:
  - Taskload refers to the number of tasks that dispatchers carry out as part of their job.
  - Workload is generally defined as the interaction between the demands of a given task (or set of tasks) and the ability of the individual operators to meet those demands. Workload takes into account the ability of the operators to meet these demands, and this in turn depends on dispatching experience, training, familiarity with the territory, stress, fatigue, and a host of other factors that affect a dispatcher's ability to meet the task demands.
- It is postulated in this study that the above-mentioned distinction lies on a continuum rather than being an absolute distinction. The MWLI does not only consider task factors but takes into consideration factors such as training (years' experience) and fatigue

(shift). The MWLI therefore leans towards the workload end of the continuum. It was deliberately decided not to include personal factors but to include only information that could be objectively collected. Similar to the FRA's requirement for a tool to collect taskload data (Reinach, 2001), a major consideration in the Spoornet project was that the tasks used in the workload assessment tool must be observable, quantifiable, and quick and unobtrusive to collect.

Authorisation weight	15.00
Tel/radio comms weight	5.00

Centre Id	No of data trans-actions (Rimas + ETA/ETD)	No of authos	Weighted no of authos	No of other tel/radio comms	Weighted no of comms	Total no of actions (weighted)	Moderators											Work-load Index
							Shift worked	Experience	Interface complexity	Running times	Crossing places	Platform Location	Authos vs Crossings	Type and Mix	Loco Depots	Shun-ting	Topo-graphy	
							12%	18%	5%	8%	6%	3%	11%	9%	10%	14%	4%	100%
1	5	34	510	204	1020	1535	1.080	1.030	1.017	1.060	1.000	1.030	1.110	1.045	1.050	1.117	1.020	2629
2	0	9	135	50	250	385	1.080	1.030	1.033	1.080	1.000	1.000	1.000	1.015	1.000	1.117	1.020	553
3	16	97	1455	345	1725	3196	1.080	1.060	1.050	1.030	1.000	1.030	1.110	1.045	1.075	1.117	1.020	5789
4	16	15	225	100	500	741	1.080	1.000	1.050	1.080	1.000	1.000	1.044	1.000	1.050	1.117	1.040	1155
5	0	9	135	9	45	180	1.080	1.030	1.050	1.060	1.000	1.030	1.044	1.000	1.050	1.117	1.000	281
6	4	38	570	271	1355	1929	1.080	1.000	1.050	1.080	1.000	1.012	1.110	1.045	1.050	1.140	1.000	3320
7	3	20	300	130	650	953	1.080	1.030	1.050	1.000	1.000	1.000	1.088	1.015	1.075	1.117	1.000	1476
8	0	35	525	146	730	1255	1.080	1.030	1.033	1.080	1.000	1.030	1.088	1.045	1.050	1.140	1.020	2228
9	24	39	585	297	1485	2094	1.080	1.030	1.050	1.080	1.000	1.012	1.110	1.045	1.075	1.117	1.000	3722
10	18	19	285	366	1830	2133	1.080	1.030	1.050	1.060	1.000	1.000	1.088	1.045	1.050	1.140	1.020	3666
11	7	45	675	325	1625	2307	1.080	1.180	1.050	1.060	1.060	1.030	1.110	1.045	1.075	1.117	1.040	5174
12	5	13	195	264	1320	1520	1.080	1.000	1.000	1.080	1.000	1.000	1.044	1.000	1.050	1.117	1.020	2214
13	0	6	90	8	40	130	1.080	1.000	1.033	1.080	1.000	1.000	1.000	1.000	1.050	1.000	1.040	171
14	2	46	690	222	1110	1802	1.080	1.030	1.050	1.080	1.060	1.030	1.110	1.045	1.050	1.117	1.020	3443
15	0	71	1065	82	410	1475	1.080	1.030	1.033	1.080	1.060	1.030	1.110	1.045	1.050	1.117	1.040	2828
16	0	42	630	327	1635	2265	1.080	1.180	1.017	1.080	1.060	1.030	1.110	1.045	1.050	1.023	1.020	4399
17	10	8	120	23	115	245	1.080	1.060	1.033	1.080	1.000	1.000	1.044	1.045	1.050	1.023	1.020	374
18	20	31	465	261	1305	1790	1.080	1.030	1.017	1.060	1.000	1.012	1.088	1.045	1.075	1.140	1.020	3086
19	9	8	120	88	440	569	1.080	1.060	1.000	1.080	1.000	1.030	1.044	1.045	1.050	1.023	1.020	866
20	0	8	120	91	455	575	1.080	1.030	1.033	1.030	1.000	1.000	1.000	1.090	1.000	1.140	1.020	863

Table 3.9: Calculated MWLI

Table 3.10: Values and interpretation of MWLI elements

	Low centre		*High* centre	
	Value	**Interpretation**	**Value**	**Interpretation**
Number of data transactions	0	Zero data transactions	16	16 data transactions
Number of authorisations	6	6 authorisations	97	97 authorisations
Weighted number of authorisations	90	6 × 15 (weight of authorisation)	1455	97 × 15 (weight of authorisation)
Number of other telephone/radio communications	8	8 communications	345	345 communications
Weighted number of communications	40	8 × 5 (weight of communication)	1725	345 × 5 (weight of communication)
Total number of actions (weighted)	130	∑ weighted authorisations and weighted communications	3196	∑ weighted authorisations and weighted communications
Shift worked	1.080	06:00-14:00 shift	1.080	06:00-18:00 shift
Experience	1.000	7-12 years	1.060	More than 12 years
Interface complexity	1.033	Single interface	1.050	Multi-interface
Running times	1.080	Uniform running times; short	1.030	Varying running times; long
Crossing places	1.000	Uniform crossing places	1.000	Uniform crossing places
Platform location	1.000	No platforms	1.030	More than 50% of crossing places have platforms
Authorisations vs. crossing places	1.000	Low impact according to matrix	1.110	Very high impact according to matrix
Type and mix of trains	1.000	One type of train; similar priority	1.045	More than one type of train with varying priority
Locomotive depots	1.050	One locomotive depot	1.075	Locomotive depot at start and end
Shunting	1.000	No shunting activities	1.117	Private sidings and other shunting
Topography	1.040	Hilly terrain; high-density built-up environment	1.020	Hilly terrain; small towns few and far between
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